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STUDIES OF INTERACTIONS OF CERTAIN SITE FACTORS AND YOUNG LOBLOLLY PINE (*PINUS TAEDA* L.) PLANTATIONS

By

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359775

CONTENTS

Page

Introduction.. 2

Review of Literature.. 4

  Effects of Site Factors on Tree Growth........................ 4

  Influence of Forest Stand on Site Factors..................... 8

Outline of the Investigation.................................... 18

Description of Experimental Areas............................... 21

Studies of Microclimatic Factors................................ 24

  Selection of the Meteorological Station Locations............. 25

  Methods of Observations....................................... 27

  Results of Observations....................................... 30

    Air Temperatures.. 30

    Atmospheric Humidity.. 38

    Precipitation... 60

    Air Movement.. 60

    Evaporation... 68

    Regression of Evaporation on Other Microclimatic Factors. 73

    Soil Temperatures... 87

    Comparison of Air and Soil Temperatures.....................109

  Discussion..119

    Air Temperature...121

    Atmospheric Humidity..123

    Precipitation...123

    Air Movement..125

    Evaporation...126

    Soil Temperature..129

359775

CONTENTS (Continued)

Page

Studies of Soil Factors....................................132

Methods of Study...134

Results of the Study.......................................138

Soil Profile...138

Physical Properties..140

Chemical Properties..144

Special Studies of the Surface Soils.......................144

Soil Moisture..150

Discussion...153

Studies of Tree Growth.....................................157

Methods of Study...157

Results..158

Studies of Lesser Vegetation...............................167

Summary and Conclusions....................................175

Appendix...180

Literature Cited...211

STUDIES OF INTERACTIONS OF CERTAIN SITE FACTORS AND YOUNG LOBLOLLY PINE (*PINUS TAEDA* L.) PLANTATIONS

INTRODUCTION

Loblolly pine (Pinus taeda L.) is an important species for wood supply in the southeastern United States. Its economic importance in timber supply was emphasized by Ashe (1915). Although it reproduces very easily in old fields, in certain cases it fails to establish itself, and it is necessary to restock the stands by planting (Mattoon, 1926). Ashe (1915) has discussed the silvical requirements of this species rather thoroughly, but very little is known about the effect of site and development of young trees after planting, especially the effects of soil characteristics on the development of young plantations of this species.

It is a well known fact that soil plays a very important part in forest planting. Since the recent development of forest soil science, more and more stress has been laid on soil factors in connection with tree growth. Climate determines the range of a tree species, but soil conditions limit its occurrence (Toumey and Korstian, 1937, p. 75).

Not only environment plays a very important part in determining the development of vegetation, but vegetation itself also modifies the environment in the course of its development (Weaver and Clements, 1937, p. 235). In a similar manner a forest stand, either naturally or artificially

established, will modify or change the site factors in different stages of its development which is known as forest reaction (Toumey and Korstian, 1937, p. 195). It is quite possible to correlate certain changes in site factors with a definite stage of development of a forest stand. The changes in duration and intensity may not be significant in all site factors and in all stages, but it is quite certain that some of them will be changed to a considerable extent in certain stages during the development of a forest stand.

The purpose of the present study is two-fold: (1) to determine the effects of different soil characteristics on the growth of young loblolly pine, and (2) to find out how many and to what extent the site factors have been changed by the development of a young loblolly pine stand. As a result it might be possible to determine what kind of silvicultural operations would be necessary to improve the quality of the stand at different stages of its development.

The investigation includes a study of the characteristics of different soil types in open field and under young planted pine stands, a comparison of micro-climatic conditions in the unplanted and planted areas, a comparison of several phases of tree development on different soil types, and a comparative study of the lesser vegetation under different soil conditions in the young plantations.

REVIEW OF LITERATURE

Effects of Site Factors on Tree Growth

The problem of effects of climatic factors on tree growth has been discussed so much that it is impossible to review all the literature in connection with the present study. A comprehensive review was given by Coile (1936a) in his study of the effect of rainfall and temperature on the annual radial growth of pine in the southern United States. From his data he concluded that the annual growth of loblolly pine in southwestern Louisiana is influenced mostly by fluctuation of the total rainfall during the period from January to May, inclusive. Increase in rainfall above the mean usually results in an increase in growth under any given condition of temperature. Less than average rainfall usually results in subnormal annual growth under a given temperature. Low growth is usually associated with high temperatures and more than average growth is associated with low temperatures. (For more general references, see Toumey and Korstian, 1937).

Soil has long been recognized as an important factor of forest sites, particularly in the European countries where much attention has been given to developing forestry practices which will maintain or improve

the condition of forest soil. In the United States the relation of soil to forestry has not been given much attention, although numerous investigations have pointed out that various species of trees have certain soil preferences and that the composition of a forest type is influenced by character of the soil. Many of these conclusions were based largely on observations. More recently, however, investigators have studied the effect of certain soil characteristics on the occurrence and rate of growth of forest trees.

Haig (1929), working in Connecticut, found that the site index for young red pine (Pinus resinosa Sol.) stands could be correlated with the colloidal content of the A, B, and C horizons and with the averages of combinations of these horizons, but concluded that the textural grades of the A horizons (silt and clay content) which showed reasonably close correlation with site index was more practicable of application.

Auten (1930) found that the rate of growth of hardwoods in Pennsylvania was materially effected by soil type, but that for a given soil type, growth was not necessarily uniform. This lack of uniformity was believed due to variation in the moisture content of the soil, caused by such factors as slope and aspect.

Hicock and others (1931) working on the same subject as that of the work of Haig, found that the character of the subsoil did not have a controlling influence on site index, and concluded that "as the trees become larger the character of the subsoil may exert greater influence." They also found that the silt-plus-clay content of the A horizon as determined by the Bouyoucos method showed a fairly good correlation up to 25 percent, but that above 25 percent there was no correlation. Colloidal content of the A horizon showed practically no correlation with site index.

A positive correlation between the moisture equivalent of the A horizon and site index was found. The total nitrogen content of the A horizon showed a better correlation with site index than any other factor studied by them. In general these investigators observed fairly good correlation between low site index values and low values of the factors they studied.

Westveld (1933) studied the yield, growth, and occurrence of different forest types on 23 soil types in the upper penninsula of Michigan and stated that the relationship between soil characteristics and forest composition and growth was sufficiently conclusive to establish general principles for forest land classification and silvicultural practices.

Diebold (1935) found that in New York State a definite relationship existed between different soil types and the type of humus layer, the amount of windfall, and the rate of survival in forest plantations.

Coile (1935) found that the quotient obtained by dividing the silt and clay content, or the "total colloidal" content (Bouyoucos method) in percentage of B_1 horizon, by the average depth in inches below the surface at which that horizon was encountered was found to be a reliable measure of site quality for shortleaf pine on the soils occurring in the Duke Forest near Durham, North Carolina.

Turner (1936) found that the rate of growth of shortleaf pine and loblolly pine in Arkansas was correlated with soil type. Areas affording the highest site indices were those on soils that are immature, flat, of high silt or silty sand content with permeable subsoil. Generally these soils had been farmed little or none.

Scholz (1937) found that red and chestnut oaks in the Black Rock Forest cover area had made more rapid growth on clay loam than on heavy clay loam or clay soils.

The effect of the chemical nature of the soil on tree growth has long attracted the attention of European investigators. Fliche and Grandeau (1873, 1874) studied the influence of chemical composition of the soil on the growth of maritime pine and chestnut. They found that both pine and chestnut were thriving better on sandy soil than on calcareous soil. Their explanation was that the calcareous soil had too high a calcium content which interferred with the absorption of other necessary nutrient material.

To substantiate Henne's (1892) and Badoux's (1895) work, Burger (1930) made extensive chemical and physical analyses of several types of soil used for experimental growing of trees in the nursery. By correlating the rate of tree growth and chemical nature of the soil he reached the following important conclusions: namely, that nitrogen was a very important factor in the growth of pine, spruce, and fir; that phosphoric acid was very important for the growth of white pine; that oak and chestnut preferred soil with less calcium; that ash, Norway maple, and Carpinus depended very much upon the potassium and phosphoric acid content of the soil for their growth; that beech and basswood thrived better on soils rich in calcium if the physical properties were favorable. In general, chemical soil conditions favorable for the growth of young trees were found to be calcium, nitrogen, and phosphoric acid contents.

Valmari (1921) analyzed a great number of soil samples collected from many sample plots located in different forest types in Finland. The chemical composition of these soils showed a decidedly quantitative difference. Ilvessalo (1923) used his data and found that there was a definite correlation between annual volume growth, and the nitrogen and calcium contents of the soil. The correlation of growth with the amount of electrolytes and loss of ignition was not very significant, and there was no

correlation with potassium and phosphorus content of the soil.

Influence of Forest Stand on Site Factors

Although little information has been published concerning the effect of forest cover, during the course of its development, on physical properties of soils, many investigations have been made on physical differences between forested and cleared land. Comparing fully stocked forest stands and cleared land, Hoppe (1898) found that water-absorbing power of forest soil was lowered after clearing. The cause was attributed to decrease of humus in the soil when it was exposed to the sun and wind after clear-cutting. He confirmed his supposition by an experiment in which he added different amounts of humus to a number of soils of different textural grade, and determined their volume weight and water-absorbing power. He found that volume weight decreased with increase of humus content, while water-absorbing power increased with soils of all textural grades he used. In a series of researches on the soil of cultivated land, heath, and forest, Albert (1912, 1913) found that a good forest soil had a higher pore volume than that of the open land. The work of Tschermak (1920) showed the same result; namely, that soil just within the edge of a forest had a considerably higher pore volume than that of adjacent cleared land.

In a series of studies to compare forest soils with those of open land, Burger (1922) found that there was very little difference in volume weight and pore space of these two kinds of soil, but there was a great difference in air capacity and permeability. He explained that while the pore volume of the two soils was not very much different, the kinds of pores were very unlike. The higher percolation of forest soil was chiefly due

to the presence of a system of worm channels, root cavities connected to form very efficient water passages. Burger (1929) showed that soils in mature coniferous stands absorbed 63.5 percent of their weight in water while pasture soil absorbed only 8.8 percent.

Auten (1933), also, found forest soils to be much more porous and permeable than those of adjacent fields. A large degree of the soil porosity was found to be regained 20 to 25 years after plantations of forest trees had been established on cultivated lands.

A forest stand changes the chemical properties of the soil chiefly through the addition of leaf litter to the soil. Through the process of decomposition, the nutritional constituents of the litter are returned to the soil. As the litter of different tree species varies considerably, both in chemical composition and in rate of decomposition, forest soil under cover of different tree species will have quite different characteristics. Interest was first aroused by description of the soil variations under different forest covers. Mueller (1887) first noticed the differences of soil under beech forests, coniferous forests, and heaths in Denmark. In the United States Fisher (1928) first reported soil changes under white pine stand as it was succeeded by a mixed hardwood stand in central New England. These changes consisted of two contrasting conditions in the humus layers and the adjacent dark brown horizons or top soil--under the pine, a heavy accumulation of litter with a thin top soil; under the succeeding hardwood, little or no organic material and with a deep top soil.

Following Fisher's report, Griffith, Hartwell, and Shaw (1930) made a detailed study of these soil changes. They found that the organic matter of the enriched zone in the soil under hardwood stands was much higher than that under pine stands. The total nitrogen content of the hardwood

soil is also slightly higher than that under the pine stands. The soil under pine stands had a wider organic matter-nitrogen ratio than that under the hardwood stands.

In connection with a study of the advisability of using pure beech or spruce or a mixture of these two species, Nemec and Kvapil (1925) found that in the humus layer, the nitrogen content was highest in a spruce stand, least in a beech stand, and intermediate in a mixed stand. In the mineral soil, however, they found that the nitrogen content was highest in soil under the mixed stand, least in that under the spruce stand. intermediate in that under the beech stand. In a later study of similar nature, Nemec and Kvapil (1926), also, stated that the soil under a pure pine stand without beech undergrowth showed a lower nitrogen content than that of an adjoining pine stand with beech undergrowth, which according to the annual increment was placed in a higher site class.

In a mixed planting of black locust and catalpa, Ferguson (1922) noticed that the height of the catalpa trees decreased as their distance from the black locust increased. By analyzing the soil he found that the total nitrogen content decreased gradually in slight amount as samples were taken farther and farther away from the black locust trees. His observation was confirmed by McIntyre and Jefferies (1932). Their data showed that both total nitrogen content and nitrifying capacity of the soil were increased under black locust trees. Chapman (1934), working in Indiana and Ohio, found the same result in mixed planting of black locust and other forest trees. Another possible explanation of the higher nitrogen content of the soil under such plantings, in addition to the nitrogen-producing activity of the root tubercles, is that the leaf litter of black locust is found to contain a high percentage of nitrogen (Gustafson, 1935).

In a recent study Garman and Merkle (1938) found that not only was the nitrogen content alone affected by the litter of black locust, but the mineral nutrients were also richer in soil covered with black locust litter as compared with that not covered.

Auten (1933b, 1934), in comparing forest soils and cultivated soils, reported that in the A_1 horizon the content of the replaceable calcium and magnesium was much higher in the forest soil, but in the A_2 and B_1 horizon, there was more replaceable calcium and magnesium in the cultivated soil.

Although the acidity of the soil depends largely upon the nature of the parent material from which it is derived, forest cover also plays an important part. As reported by Nemec and Kvapil (1924), the humus or mull layer of closed coniferous stands was much more acid than that of hardwood stands. Acidity of the same layer in mixed stands of softwoods and hardwoods showed lower acidity than pure stands of conifers, and was very close to that of the hardwood stands. The acidity of the mineral soil below this layer is lower in mixed stands than in the soil from either of the two pure stands. In a later report, Nemec and Kvapil (1925) found that both active and exchangeable acidity were higher in the soil under pure spruce stands than in that of the pure beech or mixed beech and spruce stand.

Griffith and others (1930), and Coile (1933) have noted an increase in the acidity of the soil under pure pine stands with increasing age of the stand.

The forest cover also influences, besides soil proper, such site factors as soil temperature and soil moisture, as these factors inside a forest stand are compared with the same in the open. The forest cover may influence soil temperature through the shade of the living vegetation, and

through depth of litter. Pearson (1914), working in a ponderosa pine forest in Arizona, found that the soil temperature at a depth of 2 feet throughout summer and autumn was lower inside a forest than in the open. Li (1926) found that forests greatly lowered soil temperature from July to October, particularly at the surface. His observations also showed that the daily range of surface soil temperature was also greatly reduced by forests, particularly in the summer. MacKinney (1929) reported that the litter cover raised both the mean maximum and mean minimum surface temperatures in the autumn, and lowered them in the spring, while the subsoil temperatures were raised. Such observations are generally in accordance with European observations as reviewed by Harrington (1893). In a 50-year old paper birch-white pine stand in Hamilton County, New York, Baldwin (1933) observed that soil temperature at one foot below the surface from June to August was 5 degrees F. lower inside the stand than in the open.

In a recent publication Schubert (1932) stated that in very severe weather soil temperature under forests was much more moderate than that in the open. Comparing some old data taken from June to August in the open and in a beech stand, Burger (1933a) reached the conclusion that the protective action of the canopy and the litter cover against heating of the surface soil in the summer was about equal to that of a soil layer 1 meter thick in the open country.

The amount of soil moisture lost through transpiration by forest trees is considerable. Burger (1925) made an estimate based on a 100-year old stand of site quality II. He showed that spruce could use from 1,900,000 to 2,400,000 kilograms; oak, 1,200,000 kilograms; and pine 470,000 kilograms, per hectare per year. By comparing forested and unforested areas in the growing season it is usually found that soil moisture is higher in the latter.

Comparing the soil moisture content from samples obtained in the open and beneath pine stands differing from 25 to 120 years of age, Ebermayer (1889) found that forested areas contained considerably less moisture during all seasons of the year. The difference was greatest during late summer and early autumn. He obtained comparable results in beech stands. In connection with a study of the succession of forest associations, Fuller (1914) found the percentage of growth water (total soil moisture minus the wilting coefficient) was higher in a prairie than in the forest associations which he studied in Illinois. Halden (1926) studied soil moisture by collecting samples under forest cover and at varying distances from the forest margin. He concluded that in summer the soil under forest cover was drier than that in the open, at least to a depth of 80 cm. Both in the open and in the forest the surface layer is more moist than the subsoil. During periods of drought the distribution of moisture at the surface may be reversed in the open.

The difference in soil moisture between the open and the forested area is especially distinct in the dry period, as stated by Craib (1929). According to his observations the open soils contained considerably more moisture than the forest soils, the difference was greatest in the upper soil layers, and became progressively less with increase in depth. He also stated in his report that during the driest periods of the year there was more than twice the actual volume of moisture in the first 90 cm. of soil available to plants in the open than in the forest. Shear and Stewart (1934) reported that forest trees may affect soil moisture content at depths as much as from 7 to 10 feet below the surface.

Forest meteorological observations have been conducted in European countries since the late fifties of the last century. From such observations Fernow (1893) was able to draw the conclusion that under tree crowns,

the annual range of air temperature is smaller in the forest than in the open, and the range is more affected than the average absolute temperature. Muttrich (1890), after studying 15 years' records kept by several stations in northern Germany, found that the monthly mean maximum temperatures were always lower, and the monthly mean minimum temperatures were always higher in the forest than in the field throughout the year. His readings were taken 1.8 meters from the ground in both softwood and hardwood stands. Results obtained by Li (1926) in the Yale Forest near Keen, New Hampshire, agreed with Muttrich's conclusion. Li also found that the mean monthly temperatures were lower in the forest in July, August, and September, but higher in October. Contrary to their observations, Pearson (1914) found the mean maximum temperature in western yellow pine forest in Arizona and New Mexico to be about 1 degree F. higher than that in the open.

Summarizing a 20 years' meteorological record for a beech stand and in an adjacent open place in a nursery in Adlisburg, Switzerland, Burger (1932) reported that the mean air temperature for six months from April to September, inclusive, was 1.2 degrees C. lower at breast height and 1.3 degrees C. lower near the surface of the soil in the forest than in the open area. The mean maximum temperature for this period was 3.3 degrees C. lower, and the mean minimum for the same period was 2.4 degrees C. higher near the soil surface and 0.7 degree C. higher at breast height in the forest than in the open.

As a general conclusion it can be said that forest cover undoubtedly has a moderating influence on air temperature.

Plant ecologists generally recognize that relative humidity inside a vegetation cover is usually higher than in the free atmosphere. This is

partly due to the transpiration of the plants and partly due to the stagnant condition of air within a plant community. Such a conclusion is verified by observations made by Krauss (1911) and Stocker (1923). The same condition is found in a forest stand. As stated by Rubner (1934 p. 73) the relative humidity is higher inside a forest than outside. Following Muttrich's (1875-1889) observations he gave differences of from 1 to 8 percent in different kinds of stands and in different seasons of the year. More quantitative data given by Harrington (1893) and Zon (1927) from old European records substantiate the same point.

It is generally known that wind velocity is much less inside a forest than in the open. Schubert (1922) showed that the wind velocity in a beech grove 4 meters high was only 22 percent at the 2.4 meter level, and 13 percent at the 0.2 meter level, as compared to that in the open area. Geiger (1927) also stated that the total slowing effect of the forest on wind velocity was chiefly in the upper portion of the crown canopy. His observations showed that from the lowest point of the crowns down to the soil surface (from 10.55 to 1.10 meters above the ground) the wind velocity was almost the same. He also showed that the vertical distribution of wind force in a forest varied with different wind velocity. When wind velocity is low, air movement within a forest is uniform; when it is high, the slowing effect within the stem space is lessened. Based on observations made in an oak stand Geiger and Amann (1931) found that the frequency of air calm hours (average wind velocity for the hour is 0.7 meter per second or less) increased considerably on passing from above the crown into the canopy. They also found the wind velocity between stem space under the crown higher in a pure oak stand than in another one with beech under-planting, but found the reverse to be true with wind velocity above the crown.

That forests have a very significant effect in reducing evaporation is very obvious. The less disturbed air current, the higher relative humidity and lower air temperature in forests, are all favorable conditions tending to reduce the rate of evaporation. As given by Harrington (1893) from some German records, based on an average, from May to September, over a period of 10 years (1879-1888), the evaporation from free water surface in forests was only 39 percent of that in the open.. Based on 14 years' record, Schubert (1917) found that the evaporation in beech forest as compared with that in the open was 55 percent in the winter, 51 percent in the spring, 62 percent in summer, and 60 percent in the autumn, while a similar comparison in a pine stand gave percentages of 44, 47, 50, and 48, respectively. The averages for the year were 57 percent for the beech stand and 48 percent for the pine stand. By comparing the differences of the monthly means (open area minus stand value) in the year, Schubert (1925) found that the highest value occurred in June, and the lowest in January and December, for both coniferous and beech stands. According to his data the difference in evaporation in the coniferous stand and in the beech stand was only apparent in June, July, August, and September, while in all the other months of the year the evaporation is almost the same in both stands. Working on some old data taken in Switzerland, Burger (1933b) reached a similar conclusion. He reported that the mean annual evaporation in the beech stand was only 40 percent, in the spruce stand 27 percent, of that in the open country. For the summer half of the year the evaporation in the beech stand was 38 percent, in the spruce stand 28 percent, while in the winter half of the year it was 45 percent in the beech stand and 25 percent in the spruce stand, as compared with that in the open country. Based on observations made in Hamilton County, New York, Baldwin (1933) found that the evaporation rate for the three months, June, July, and August, averaged 34.5 c. c. in a paper birch-

white pine stand and 83.2 c. c. in an adjacent open area.

Yapp (1909) studying the evaporation rate at different heights above the ground level in Wicken Fen, England, found that the ratios of evaporation rate above the vegetation level, at the middle of the vegetation, and at the soil surface, were 100: 34.8: 6.6 for 1907, and 100: 56.2: 14.7 for 1908. Fuller (1914) reported that the mean weekly ratio of evaporation for three seasons between the beech-maple forest and edaphic prairie was 1: 1.79; or the evaporation rate in the forest was only about 58 percent of that in the prairie.

OUTLINE OF THE INVESTIGATION

The basic idea in making this investigation was to study the interrelations between site factors and the development of planted forest stands. It was planned to go into two phases of the problem, first the interrelation between the climatic factors and the development of the planted stands, and second that between the soil factors and the development of the stands. Since this investigation had to be conducted in a limited area, it is natural to overlook the effects of climatic factors on the development of the planted stands. Along the line of the first phase of this investigation the work was entirely restricted to the study of modification or change in the microclimatic conditions within the plantation. This was accomplished by establishing two adjacent meteorological stations, one in an open area and the other in a plantation. The areas were so chosen that they were as closely similar as possible in such features as soil, topography, slope, and exposure.

In the second phase of the investigation more emphasis was put on the effects of soil characteristics on the development of the young trees. This was so planned chiefly because the plantations studied were very young, less than 10 years old, and not very much change in soil was to be expected

in such a short time. In order to study the effect of soil characteristics on the growth of young trees, plantations were chosen so that they were on different types of soils. Plantations on three soil types, Creedmoor sandy loam, Whitestore clay loam (eroded phase), and Georgeville stony clay, were studied. It was found that the appearance of trees on some seriously eroded spots in the plantations was quite different from that on uneroded places of the same soil. Hence it was decided to distinguish the extent of erosion of the soils. In the three soil types mentioned above, uneroded and eroded plots were chosen in the plantation on Georgeville stony clay; since there was no eroded place in the plantation on the Creedmoor sandy loam, Whitestore clay loam was chosen to represent the eroded phase of that soil. These two types were so much alike that they were mistaken as one type at the beginning of this work. Studies of soil profile, detailed physical and chemical properties were carried out in the field and in the laboratory. Soil moisture and soil temperature were also determined. Effect of planting on the soil characteristics was obtained by comparing conditions in a plot in an abandoned field on Creedmoor sandy loam with those in the plantation on the same type of soil.

For the study of tree growth as influenced by soil conditions, diameter breast-height and height of trees were measured on the different soils studied. Number and size of roots, and their distribution in the soil profile were also recorded for comparison, this was done by excavation of soil pits about two to three feet from the trees.

A list of the conditions investigated in this work follows:

1. Microclimate
    - a. Air temperature
    - b. Relative humidity and vapor pressure deficit
    - c. Air movement

    - d. Precipitation
    - e. Evaporation
    - f. Soil temperature
- 2. Soil
    - a. Mechanical analysis
    - b. Volume weight, air capacity, and water-holding capacity
    - c. Moisture equivalent
    - d. Wilting percentage
    - e. Total carbon and organic matter
    - f. Soil reaction (pH)
    - g. Soil moisture
- 3. Tree growth
    - a. Height and diameter
    - b. Roots
- 4. Lesser vegetation.

A detailed account of the methods used and results obtained are presented in subsequent sections.

DESCRIPTION OF EXPERIMENTAL AREAS

The investigation was made in the Durham Division of the Duke Forest near Durham, North Carolina. The Durham Division which contains 3,328.9 acres, is the largest of the three divisions of the Forest. The general physical environment of this Forest has been described by Korstian and Maughan (1935). Elevations in this Division range from about 400 to 650 feet above sea level. The slate formation, with its associated acid and basic igneous intrusives, underlies the northern part of this Division, and Triassic sandstone underlies the southern part. The surface varies from undulating to gently rolling.

The climate is mild with long summers and short winters. Zero temperatures are rare and temperatures above 100 degrees F. are not uncommon during the summer months. The mean annual temperature is 59.1 degrees F. at Durham averaged from a 9-year record. For the same period the mean annual precipitation averaged 41.12 inches with a 24-year record. The precipitation as a rule is rather uniformly distributed throughout the year.

Because there are two phases included in this investigation, namely, the comparison of microclimatic conditions between an open and a planted area, and the comparison of the growing condition of trees planted on different soils, the experimental sites selected for observations must fulfill the

two following conditions: the physical conditions of the open and planted areas should be strictly alike, and the plantations selected on different soils should be identical in respect to species, age, stock used, method of planting, and spacing. After studying the file records of the Duke Forest, and examining the plantations in the field, Plantations 4 and 6, located in Compartments 51 and 67, were selected for study.

Compartment 51 is located at the junction of the Erwin Road and State Highway 751 in about the middle part of the Durham Division of the Duke Forest. More than two thirds of the area comprised in this compartment is abandoned fields which formerly supported farm crops, mainly tobacco and cotton. The remaining one third is occupied by pine stands either of pure loblolly pine or a mixture of loblolly and shortleaf pines. It was planted to different species of pine after the area was acquired by the Duke Forest. Planting work began in 1931 and by 1933 practically all abandoned fields were planted except a small area about 1.4 acres on the southeastern border. This unplanted area was selected to represent the open area, and Plantation 4 located near the south end of this compartment immediately adjacent to this area, was chosen to represent the planted area for microclimatic observations. Both these places are on the same soil type, Creedmoor sandy loam, and possess a more or less level topography. This place will be designated as Location 1 hereafter.

Plantation 4 of Compartment 51 covers an area of 6.05 acres. It was planted to loblolly pine in January 1931. One-year old seedlings were used. The stock came from the state nursery near Clayton, North Carolina. Trees were planted in rows with a spacing of 6 feet by 8 feet. When these studies were started in July 1936, the trees had reached an average height of 15 feet.

Compartment 67 is located near the northern end of the Durham Division, about 4 miles away from Compartment 51. This will be called Location 2 hereafter. In this compartment Plantation 6 was selected as the area for soil observations and study of tree growth to be compared with Plantation 4 of Compartment 51. This area was selected because it was planted during the same season as Plantation 4 of Compartment 51, but on different soil type. It was the one most comparable. The soil of this plantation is Georgeville stony clay derived from slate of the Carolina slate belt. Previous to planting, this area was a cultivated field which had been abandoned several years and covered with a dense stand of broom-sedge (*Andropogon* spp.), with scattered patches of briers (*Rubus procumbens*), and scattered small red cedar (*Juniperus virginiana* L.), sassafras (*Sassafras variifolium* (Salisb.) Kuntze), black gum (*Nyssa sylvatica* Marsh.), and hickory (*Hicoria* spp.) trees. In February 1931 it was planted with 1-year old loblolly pine seedlings which were obtained from the state nursery near Clayton, North Carolina. A 6-foot by 6-foot spacing was used. The planting covered an area of 2.92 acres.

Both of these plantations were heavily infested with tip moth (*Rhyacionia frustrana*) from 1933 through 1935, which hindered the growth and development of the trees. By 1936 the trees appeared to have recovered and since then have resumed normal growth.

STUDIES OF MICROCLIMATIC FACTORS

The importance of microclimatic study with special reference to its practical application in forestry and agriculture has been stressed by Geiger in his books dealing with this subject (Geiger, 1927, 1930). The necessity to distinguish the microclimatic observations from those obtained at ordinary weather stations was explained by him as follows: (1) the meteorological data supplied by the ordinary weather stations only represent the climatic conditions in which men live, as what was named by him the "human climate" (Menschenklima), and do not represent the true conditions in which the plants exist, as what he called the "Phyto-climate" (Pflanzenklima); (2) the underlying physical laws will be different for the microclimate and macroclimate, although studies along this line have just begun, and not very many convincing conclusions have as yet been deduced. By microclimate is meant atmospheric conditions in a limited area and their changes in the air strata very close to the soil surface, generally not more than two meters high. Three main factors are responsible for the existence of microclimate; namely, topography (orography), human influence, and plant cover. The influence of plants on microclimate is based on three facts: (1) the physical quality and form of a plant-covered surface is different from that

of a bare soil; (2) the exchange conditions of heat in the environment of the plants are different; and (3) the air space within the plant cover develops a climate peculiar to itself (Geiger, 1930).

New methods and technique have been developed especially for microclimatic observations. All the instruments and techniques used in this investigation, however, were still the same as used for the conventional meterological observations. Since no unforeseen inaccuracy had ever been detected, it was assumed that the methods used had served the purpose very well and that there was no need to adopt new technique.

Selection of the Meteorological Station Locations

Although Geiger (1927, p. 151) has stated that it is inaccurate to study the influence of forests on climate by establishing stations inside and outside a forest in close proximity, nevertheless, such a comparative study is still worth making, if only the differences under such conditions as in the forest and in the open area are desired. It is also justified to use such a method in places where the forest stands are less extensive and mostly intermingled with open areas, such as exist in many European countries (Burger, 1933a).

For the reason mentioned above the open and planted areas selected for observation were adjacent to each other. With such a selection the possibility of variations in soil, topography, slope, and exposure, in the two areas was reduced to a minimum.

The locations selected for the meteorological observations were at Location 1 and have been described in a previous section. It was in an area covered with a planted forest stand, known as Plantation 4. This plantation was more or less rectangular in shape, covering an area of 6.05 acres. The

size and thriftiness of the trees was not uniform throughout the entire area, those in the eastern half being much taller and thriftier. The crown canopy was closed, dense, and almost reached the ground. There was not very much clear space between the ground surface and the crown canopy. It was in this part of the plantation that the meterological station was located. The station was installed near the northeast corner of the plantation. The instrument shelter and instruments not sheltered were located in a square area 25 feet by 25 feet enclosed with wire fence, except that the rain gauge was about 10 feet north of the northern side of the enclosed area. The center of this square area where the shelter was located was 42 feet from the eastern border, 96 feet from the northern border of the plantation, 520 feet from the western, and 560 feet from the southern border. On its western border the plantation was bounded by State Highway 751, on its southeastern border were plantations which were so young and open that they were not very much different from the open land. On its northern border, it was adjacent to a piece of abandoned field that had not been planted. In the open area another meteorological station was located.

The size of the unplanted area was about 1.4 acres. The land surrounding this area, except on its southern border, was mainly of an open-land character, although it had been planted to different species of very young pines. Hardly any of the trees were more than 4 feet high. The station here was set up in an area 15 feet by 15 feet square, the center of which was 384 feet from the one located in the plantation, and about 250 feet from its northern border. The shelter and other instruments were enclosed in a wire fence except the rain gauge which stood about 50 feet to the northeast outside the fence.

Methods of Observations

Before the meteorological stations were installed, it was decided that the observations should include the following records: air temperature, relative humidity, wind velocity, evaporation, precipitation, and soil temperature. Air temperature and relative humidity were recorded with a Friez hygro-thermograph and checked weekly by using maximum and minimum thermometers and sling psychrometer. Wind velocity was recorded with standard U. S. Weather Bureau three-cup anemometers. Livinston's porous cup atmometers were first used for measuring evaporation, but later was changed to U. S. Forest Service evaporimeters. Friez soil thermographs were used for recording soil temperatures.

The hygro-thermographs, soil thermographs, and maximum and minimum thermometers were installed in a standard U. S. Weather Bureau shelter which was set at a height of 6 feet from the ground. The height of the shelter was so determined after the average height of 20 trees surrounding the shelter was known. It was about midway of the height of the trees. The anemometer was installed at the same height. Two sets of atmometers, and later evaporimeters were used. One set was installed on top of a post 6 feet high, and another was put on the surface of the ground. The soil temperatures were recorded at two depths, one just beneath the soil surface and the other at a depth of 6 inches. Rainfall was measured by standard U. S. Weather Bureau Rain gauge. A duplication of the same instruments in the same position was installed outside of the plantation in the open area. The distance between these two stations was 384 feet.

All the observations obtained were put on a weekly basis. Record sheets of the hygro-thermograph and of soil thermographs were

changed weekly. The accuracy of the hygro-thermograph was checked every week with maximum and minimum thermometers in the shelter and with a sling psychrometer. The soil thermograph was calibrated in the laboratory first with ordinary air thermometers and later checked with goose-neck maximum and minimum soil thermometers during the first few weeks after they were installed in the field. Evaporation was measured weekly by recording the amount of water evaporated during that period. Wind velocity was recorded as total number of miles traveled in one week. Rainfall was measured immediately after the rain was over, and was totaled as number of inches at weekly intervals.

Daily observations on maximum and minimum soil and air temperatures were started on July 13, 1936. Air temperature was determined with maximum and minimum thermometers installed in the shelter, while soil temperature was determined with two sets of goose-neck maximum and minimum soil thermometers set at two depths in the soil. These preliminary observations were discontinued on August 31 of the same year after the hygro-thermographs were installed on July 31, 1936, and the soil thermographs were installed on August 7, 1936. All the data used in the report were from the automatic recording instruments.

Observations on evaporation and solar radiation were started on July 10, 1936. This was continued until October 27 of that year. During this whole period Livingston's black and white porous cup atmometers were used for measuring the weekly loss of water through evaporation. After October 27, 1936, U. S. Forest Service evaporimeters of the metal cup type were used because of cold weather. They were used for the remainder of the observation period.

Observations on wind velocity were started on August 11, 1936.

Tht first rainfall was recorded on August 6, 1936.

All the meterological records were kept continuously until November 28, 1937, a period of about 16 months. However, only twelve months' data were presented in the following discussion, beginning on September 21, 1936, and ending on September 19, 1937. From September 21 to December 20, it is classified as the autumn season, from December 21 to March 21 as the winter season, from March 22 to June 20 as the spring season, and from June 21 to September 19 as the summer season, each season comprising 13 weeks..

Only weekly values for all the meteorological records were used. The mean weekly air and soil temperatures were the averages of the bi-hourly observations of that week as recorded by the self-recording instruments. The mean weekly maximum and minimum values of the same items were the averages of the respective daily maximum and minimum values obtained from the recording sheets. The values of relative humidity during the day was separated from that at night. From 6 a. m. to 6 p. m. was considered as day, and from 6 p. m. to 6 a. m. as night. The weekly means of these two were obtained by averaging even-hour readings during that period for the whole week. The same method of calculation was used for vapor pressure deficit. No attempt was made to get direct readings of vapor pressure deficit. All values for this observation were obtained by the equation:

Vapor pressure deficit at temperature T = saturation deficit x vapor pressure at temperature T.

Saturation deficit values were derived from the even-hour readings of the relative humidity as recorded on the hygro-thermograph sheets, the vapor pressure values were obtained from the vapor pressure table in Handbook of Chemistry and Physics (Hodgman, 1936) and expressed in millimeter of mercury for the temperature as recorded on the thermograph sheets at the corresponding hour. Since the temperature given in the handbook was in

Centigrade, to facilitate the calculating work, a vapor pressure deficit table which gives the vapor pressure deficit values for temperatures from 19 degrees F. to 105 degrees F., and for saturation deficits from 1 percent to 90 percent (relative humidity 99 percent to 10 percent), was prepared by the writer.

In the actual calculation of all the data mentioned above, daily mean values of all the records were first calculated, and by averaging the daily mean values the weekly means were obtained.

Results of Observations

Air Temperatures:

The results of observations on air temperature are shown, in a condensed form, in Table 1, which gives the annual and seasonal average values for the mean, maximum, and minimum air temperatures during the period of observation.

By glancing through Table 1 it can readily be seen that all the average values in the plantation are higher than those in the open area throughout the whole year. The mean seasonal range between maximum and minimum air temperatures in the plantation was lower than that of the open area in autumn and winter, but the relation was reversed in the spring and summer. For either station, the highest range was in summer and the lowest in winter.

In order to test the significance of all these average values, the data from which Table 1 was condensed were further analyzed by using the method of analysis of variance (Fisher, 1936), the results of which are given in Tables 2, 3, and 4.

From the analysis of variance tables it can be determined that the

Table 1. Annual and seasonal average values for the mean, maximum, and minimum air temperatures in degrees F. at the two stations.

	In plantation				In open area			
	Mean	Maximum	Minimum	Range	Mean	Maximum	Minimum	Range
Autumn	53.08	65.04	43.26	21.78	51.56	63.17	41.18	21.99
Winter	44.69	55.04	35.24	19.80	43.54	53.41	33.57	19.84
Spring	63.34	78.49	50.24	28.25	61.72	75.56	48.62	26.94
Summer	74.92	87.97	65.56	22.41	72.91	85.17	63.32	21.85
Mean of year	59.01	71.64	48.58	23.06	57.43	69.33	46.67	22.66

Table 2. Analysis of variance of the mean weekly air temperatures.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	12966.1819	4322.0606	F = 30.23 P < 0.0000001
Residual between weeks of the same season (Error 1)	48	6863.1596	142.9825	
Total between weeks	51	19829.3415		
Differences between stations				
Between station averages	1	64.4489	64.4489	F = 80.66 P = 0.0028
Station-season interaction	3	2.3997	0.7999	F = 4.26 P = 0.01
Residual between weeks of the same season (Error 2)	48	9.0195	0.1879	
Total	103	19905.2096		

ts for between season means = 8.88[1]

ts for between station means = 1.02[2]

ts for between station means in the same season = 0.46[3]

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[1] the *s* here is calculated from error 1 based on 48 degrees of freedom.

[2] the *s* here is calculated from mean squares of season-station interaction based on 3 degrees of freedom.

[3] the *s* here is calculated from error 2 based on 48 degrees of freedom.

Table 3. Analysis of variance of the mean weekly maximum air temperatures.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	15772.3504	5257.4501	$F = 31.72$ $P < \ngtr 0.0000001$
Residual between weeks of the same season (Error 1)	48	7956.5805	165.7621	
Total between weeks	51	23728.9309		
Differences between stations				
Between station averages	1	138.4847	138.4847	$F = 49.32$ $P = 0.0064$
Station-season interaction	3	8.4236	2.8079	$F = 3.61$ $P = 0.0168$
Residual between weeks of same season (Error 2)	48	37.3346	0.7778	
Total	103	23913.1738		

ts for between season means = 9.56[1]

ts for between station means = 1.92[2]

ts for between station means of the same season = 0.93[3]

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[1] see footnote 1, table 2.

[2] see footnote 2, table 2.

[3] see footnote 3, table 2.

Table 4. Analysis of variance of the mean minimum air temperatures.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	12741.1749	4247.0583	$F = 25.19$ $P < 0.0000001$
Residual between weeks of the same season (Error 1)	48	8092.5534	168.5949	
Total between weeks	51	20833.7283		
Differences between stations				
Between station averages	1	94.4689	94.4689	$F = 152.37$ $P = 0.0012$
Season-station interaction	3	1.8543	0.6181	$F = 2.85$ $P = 0.0485$
Residual between weeks of the same season (Error 2)	48	10.3979	0.2166	
Total	103	20940.4494		

$\underline{ts}$ for between season means = 9.64[1]

$\underline{ts}$ for between station means = 1.80[2]

$\underline{ts}$ for between station means of the same season = 0.49[3]

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[1] see footnote 1, table 2.

[2] see footnote 2, table 2.

[3] see footnote 3, table 2.

differences in mean, maximum, and minimum temperatures between these two stations are statistically significant. In other words, the temperatures at these two stations were significantly different during the period of this investigation. The significance of all these differences can be understood more readily if the differences of all the average values (mean differences) are compared with their corresponding fiducial limits (ts). (Fisher, 1937; Snedcor, 1938). To facilitate such comparisons, in Table 5 are given the differences of all the average values with their corresponding fiducial limits.

In Table 5 it is shown that all the differences of the seasonal and annual means for the mean, maximum, and minimum air temperatures of the two stations are higher than their corresponding fiducial limits (ts). This proves that the differences of all these mean values of temperature between the two stations are not fortuitous. In the same table it is also shown that the greatest differences of mean and minimum temperature occurred in the summer season, while that of maximum temperature occurred in the spring. The least difference in mean and maximum temperature occurred in the winter, while that of the minimum occurred in the spring.

The weekly mean values of mean, maximum, and minimum air temperatures at the two stations are plotted in Figure 1. The highest mean weekly temperature values of the year were in the week of June 12 to June 18, 1937, with a value of 82.8 degrees F. in the plantation, and 81.0 degrees F. in the open area; maxima of 99.4 degrees F. and 94.4 degrees F., respectively, and minima of 71.0 degrees F. and 69.9 degrees F. for the two stations. The lowest mean weekly temperature values were in the week of February 22 to February 28, 1937, with a value of 36.3 degrees F. in the plantation and 34.8 degrees F. in open area for the mean; 48.3 degrees F.

Table 5. The annual and seasonal differences in air temperatures in degrees F. between the two stations.

Season	Differences (plantation - open area)					
	Mean air temperature	*ts*	Mean maximum	*ts*	Mean minimum	*ts*
Autumn	1.52	0.46	1.87	0.93	2.08	0.49
Winter	1.15	0.46	1.63	0.93	1.67	0.49
Spring	1.62	0.46	2.93	0.93	1.62	0.49
Summer	2.01	0.46	2.80	0.93	2.24	0.49
Mean of year	1.58	1.02	2.31	1.92	1.91	1.80

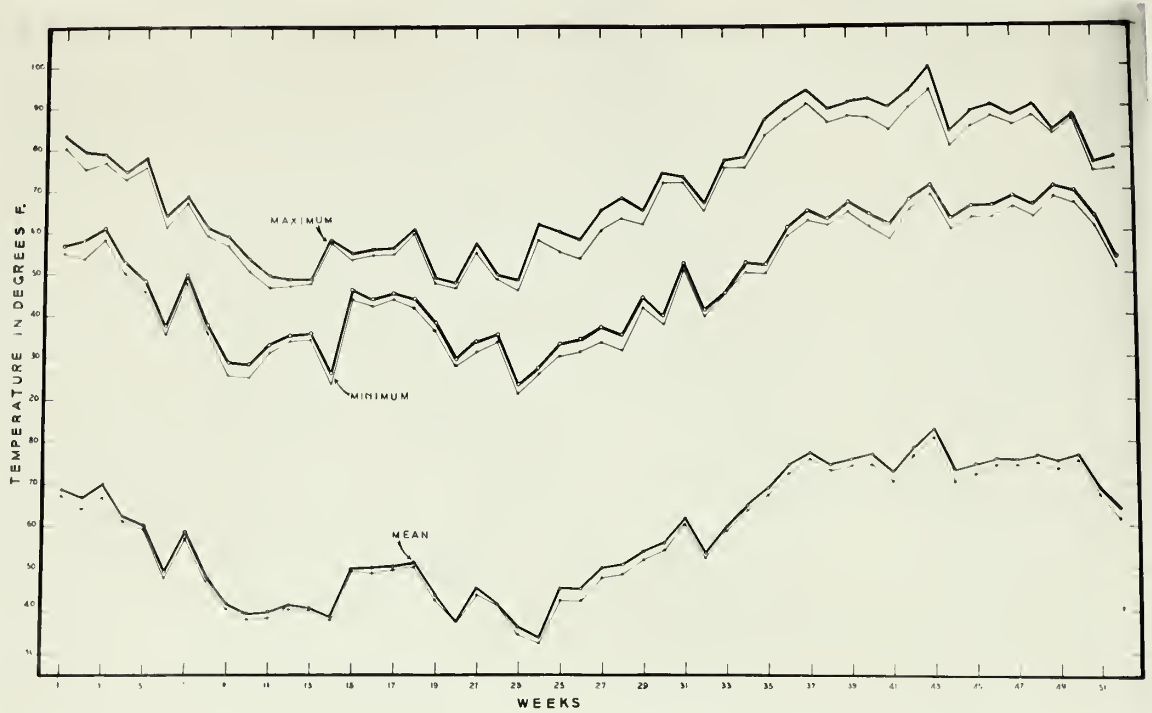

Figure 1. The weekly mean, maximum, and minimum air temperatures at the two stations from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation and the light lines represent the open area.

and 23.3 degrees F. for the maxima; and 23.3 degrees F. and 21.6 degrees F. for minima, at the two stations. The highest mean weekly range between maximum and minimum were 35.0 degrees F. in the plantation, which occurred in the week of March 17 to May 23, 1937, and 33.9 degrees F. in the open, which occurred in the week of December 28, 1936, to January 3, 1937. The lowest values for the same were 8.8 degrees F. in the plantation and 9.8 degrees F. in the open area, which occurred in the week of April 12 to April 18, 1937.

Atmospheric Humidity:

The results of observations on relative humidity in the atmosphere are summarized in Tables 6 and 7. Table 6 gives the annual and seasonal average values for the mean realtive humidity during the day and night periods at the two stations, and Table 7 gives the same values for the minimum relative humidity. The dryness of the atmosphere was expressed by vapor pressure deficit which was calculated from the daily records of temperature and saturation deficit (= 100 - relative humidity in percentage). The reason that vapor pressure deficit is preferred to relative humidity, is because it is a much more sensitive indicator of the water vapor condition of the atmosphere and undergoes greater variations with temperature changes; therefore, it can serve as a more accurate index of evaporation than relative humidity. This fact has been clarified by Livingston and Shreve (1921), Bolas (1926), Braun-Blanquet (1932), and Anderson (1936). The annual and seasonal average values for the mean vapor pressure deficit during the day and night periods at the two stations are given in Table 8, and those for the maximum vapor pressure deficit are given in Table 9.

In Table 6 two facts are evident; first, that the relative humidity,

Table 6. Annual and seasonal average percentage values for the mean relative humidity during day and night periods at the two stations.

Season	In the plantation			In the open area		
	Day	Night	Average	Day	Night	Average
Autumn	72.82	93.74	83.28	68.98	92.50	80.74
Winter	72.39	92.26	82.32	68.89	89.35	79.12
Spring	56.04	91.97	74.01	50.56	88.17	69.37
Summer	71.98	98.30	85.14	66.48	96.63	81.56
Mean of year	68.31	94.07	81.19	63.73	91.66	77.70

Table 7. Annual and seasonal average percentage values for the minimum relative humidity at the two stations.

Season	In the plantation	In the open area	Average
Autumn	53.49	49.89	51.69
Winter	56.09	52.30	54.20
Spring	39.78	37.09	38.44
Summer	52.31	50.29	51.30
Mean of year	50.42	47.39	48.90

Table 8. Annual and seasonal average values for the mean vapor pressure deficit in millimeters of mercury during day and night periods at the two stations.

Season	In the plantation			In the open area		
	Day	Night	Average	Day	Night	Average
Autumn	4.08	0.57	2.32	4.30	0.53	2.42
Winter	2.76	0.52	1.64	2.88	0.64	1.76
Spring	9.90	1.00	5.45	10.00	1.50	5.75
Summer	8.94	0.30	4.62	9.63	0.69	5.16
Mean of year	6.42	0.60	3.51	6.70	0.84	3.77

Table 9. Annual and seasonal average values for the maximum vapor pressure deficit in millimeters of mercury at the two stations.

Season	In the plantation	In the open area	Average
Autumn	8.11	8.00	8.06
Winter	5.18	5.19	5.18
Spring	15.94	15.05	15.50
Summer	17.24	15.94	16.59
Mean of year	11.62	11.05	11.33

both in daytime and at night, was higher in the plantation than in the open area throughout the year, and second, that the greater difference in relative humidity at the two stations only occurred in the daytime, because the relative humidity at night was quite uniform and very close to saturation. Table 7 also shows that the relative humidity was closer to the lower extreme in the open area than that in the plantation. The significance of such values was tested with methods of analysis of variance as in the case with the air temperatures. The results are given in Tables 10 and 11.

Although the relative humidity at the two stations seemed to have deviated considerably (about 5 percent for the annual mean), it did not necessarily mean that the dryness of the atmosphere at these two places deviated as much, because the temperatures at the two places were not identical. This fact is confirmed by Table 7 in which it is shown that the vapor pressure deficit values for these two places were very close, although the open area values still exceed those in the plantation. Table 9, however, shows that except in the winter season, maximum vapor pressure deficit values in the plantation were higher than in the open area. This means that the atmosphere was drier in the plantation than in the open area. The results of analysis of variance of the vapor pressure deficit values are given in Tables 12 and 13.

From the results of analysis of variance shown in Table 10, it can be seen that the difference in mean relative humidity between the two stations was significant. The same is true with minimum relative humidity as shown in Table 11. This conclusion will be further exemplified by comparing the average diurnal, seasonal, and annual differences between the two stations with their corresponding fiducial limits (ts). This comparison is given in Tables 14 and 15.

Table 10. Analysis of variance of mean relative humidity during day and night periods at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined based on 24-hour period				
Between season averages	3	4349.3354	1449.7785	F = 5.76 P = 0.0018
Residual between weeks of the same season (Error 1)	48	12086.3320	251.7986	
Total between weeks	51	16435.6674		
Differences between stations based on 24-hour period				
Between station averages	1	634.2729	634.2729	F = 62.79 P = 0.0042
Station-season interaction	3	30.3054	10.1018	F = 3.82 P = 0.0168
Residual between weeks of the same season (Error 2)	48	127.0414	2.6467	
Total between weeks	103	17228.2871		
Differences between day and night at separate stations				
Between day and night averages	1	37476.1569	37476.1569	F = 51.93 P = 0.0028
Day-season interaction	3	2163.6672	721.2224	F = 14.85 P 0.0000001
Day-station interaction	1	61.2592	61.2592	F = 1.26 P = 0.3272
Day-station-season interaction	3	18.5114	6.1705	F = 7.87 P = 0.8086
Remainder (Error 3)	96	4661.7062	48.5594	
Total	207	61609.5880		

Table 10. (Continued)

ts for between season means = 8.33[1]

ts for between station means = 2.57[2]

ts for between station means of the same period = 3.81 (1 percent), 7.08 (5 percent)[2]

ts for between station means of the same season = 1.21[3]

ts for between station means of the same period in the same season = 1.71[3]

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[1] *s* calculated from error 1, based on 48 degrees of freedom.

[2] *s* calculated from mean squares of station-season interaction, based on 3 degrees of freedom.

[3] *s* calculated from error 2, based on 48 degrees of freedom.

Table 11. Analysis of variance of the mean weekly minimum relative humidity at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	3926.4752	1308.8251	F = 3.50 P = 0.0221
Residual between weeks of the same season (Error 1)	48	17926.2097	373.4627	
Total between weeks	51	21852.6849		
Differences between stations				
Between station averages	1	238.1583	238.1583	F = 67.66 P 0.0000001
Station-season interaction	3	13.2908	4.4303	F = 1.26 P =0.3183
Residual between weeks in same season (Error 2)	48	168.9664	3.5201	
Total	103	22273.1004		

ts for between season means = 10.76 (5 percent)[1]

ts for between station means =0.99[2]

ts for between station means of the same season = 1.97[2]

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[1] *s* calculated from error 1, based on 48 degrees of freedom.

[2] *s* calculated from error 2, based on 48 degrees of freedom.

Table 12. Analysis of variance of the mean vapor pressure deficit at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined based on 24-hour period				
Between season averages	3	560.9511	186.9837	$F = 19.09$ $P < 0.0000001$
Residual between weeks of the same season (Error 1)	48	469.0639	9.7722	
Total between weeks	51	1030.0150		
Differences between stations based on 24-hour period				
Between station averages	1	3.5596	3.5596	$F = 6.52$ $P = 0.0815$
Station-season interaction	3	1.6372	0.5457	$F = 5.33$ $P = 0.0030$
Residual between weeks of the same season (Error 2)	48	4.9162	0.1024	
Total between weeks	103	1040.1280		
Differences between day and night at separate stations				
Between day and night averages	1	1774.1337	1774.1337	$F = 11.81$ $P = 0.0405$
Day-season interaction	3	450.5550	150.1850	$F = 37.29$ $P < 0.0000001$
Day-station interaction	1	0.0121	0.0121	$F = 332.87$ $P = 0.3272$
Day-station-season interaction	3	1.0445	0.3482	$F = 11.57$ $P = 0.8086$
Remainder (Error 3)	96	386.6558	4.0277	
Total	207	3652.5291		

Table 12. (Continued)

ts for between season means = 1.64[1]

ts for between station means = 0.32 (5 percent), 0.60 (1 percent)[2]

ts for between station means of the same period = 0.85 (1 percent), 0.46 (5 percent)[2]

ts for between station means of the same period in same season = 0.36 (1 percent), 0.23 (5 percent)[3]

ts for between station means of the same season = 0.24 (1 percent), 0.18 (5 percent)[3]

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[1] *s* calculated from error 1, based on 48 degrees of freedom.

[2] *s* calculated from mean square of season-station interaction, based on 3 degrees of freedom.

[3] *s* calculated from error 2, based on 48 degrees of freedom.

Table 13. Analysis of variance of mean weekly maximum vapor pressure deficit at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	2431.4959	810.4986	F = 23.01 P < 0.0000001
Weeks of the same season (Error 1)	48	1690.7337	35.2236	
Total between weeks	51	4122.2296		
Difference between stations				
Between station averages	1	8.4474	8.4474	F = 3.27 P = 0.1692
Station-season interaction	3	7.7413	2.5804	F = 3.47 P = 0.0221
Residual between weeks of the same season (Error 2)	48	35.6517	0.7427	
Total	103	4174.0700		

ts for between season means = 4.41[1]

ts for between station means = 1.84 (1 percent), 1.00 (5 percent)[2]

ts for between station means of the same season = 0.91 (1 percent), 0.68 (5 percent)[3]

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[1] s calculated from error 1, based on 48 degrees of freedom.

[2] s calculated from mean squares of station-season interaction, based on 3 degrees of freedom.

[3] s calculated from error 2, based on 48 degrees of freedom.

Table 14. The diurnal, seasonal, and annual differences in mean relative humidity between the two stations.

Season	Differences (In the plantation - open area)						
	Day period (Percent)	ts	Night period (Percent)	ts		Average	ts
Autumn	3.84	1.71	1.24	1.71*	1.28**	2.54	1.21
Winter	3.50	1.71	2.91	1.71	1.28	3.20	1.21
Spring	5.48	1.71	3.80	1.71	1.28	4.64	1.21
Summer	5.50	1.71	1.67	1.71	1.28	3.58	1.21
Mean of year	4.58	3.81	2.41	3.81*	2.08**	3.49	2.57

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*1 percent
**5 percent

Table 15. The seasonal and annual differences in mean minimum relative humidity between the two stations.

Season	Differences (In the plantation - In open area)	
	Percent	ts
Autumn	3.60	1.97
Winter	3.79	1.97
Spring	2.69	1.97
Summer	2.02	1.97
Mean of year	3.03	0.99

From Table 14 it is evident that almost all the differences between the different averages of the mean relative humidity of the two stations exceeded their fiducial limits at the 1 percent level except two which only exceeded the 5 percent level, and one which was not significant. From the results shown in Table 14 it would be justifiable to conclude that relative humidity was lower in the open area than in the plantation throughout the year, in the day time, also lower at night throughout the year except during autumn in which the difference was not significant.

Table 15 gives the results of a comparison of the seasonal and annual differences with their fiducial limits for minimum relative humidity of the two stations. The results show that the minimum relative humidity in the plantation was higher than that in the open area with an annual difference of 3.03 percent. This difference is shown to be significant, because it far exceeds its fiducial limit. For the same reason, the seasonal differences are also shown to be significant.

From the results of analysis of variance given in Table 12 it is shown that the difference in mean vapor pressure deficit is significant for the four seasons, and between day and night periods, rather than between the two stations. A further comparison of the diurnal, seasonal, and annual differences of mean vapor pressure deficit between the two stations with their corresponding fiducial limits is given in Table 16.

By analysis of variance it was shown that the significant difference in mean maximum vapor pressure deficit was also in four seasons, but not between the two stations (Table 13). A comparison of the seasonal and annual differences in mean maximum vapor pressure deficit of the two stations with their fiducial limits is given in Table 17.

From Table 16 it may be seen that the significant differences in

Table 16. The mean diurnal, seasonal, and annual differences in mean vapor pressure deficit in millimeters of mercury between the two stations.

Season	Differences (Open - plantation)								
	Day period	ts		Night Period	ts		Average	ts	
Autumn	0.22	0.36*	0.23**	- 0.04	0.36*	0.23**	0.10	0.24*	0.18**
Winter	0.12	0.36	0.23	0.12	0.36	0.23	0.12	0.24	0.18
Spring	0.10	0.36	0.23	0.50	0.36	0.23	0.30	0.24	0.18
Summer	0.69	0.36	0.23	0.39	0.36	0.23	0.54	0.24	0.18
Mean of year	0.28	0.85*	0.46**	0.24	0.85*	0.46**	0.26	0.60*	0.32**

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*1 percent
**5 percent

Table 17. The annual and seasonal differences in mean maximum vapor pressure deficit in millimeters of mercury between the two stations.

Season	Differences (Open - plantation)	ts	
Autumn	- 0.11	0.91*	0.68**
Winter	0.01	0.91	0.68
Spring	- 0.89	0.91	0.68
Summer	- 1.30	0.91	0.68
Mean of year	- 0.57	1.84*	1.00**

---

*1 percent
**5 percent

mean vapor pressure deficit between the two stations were only those in the spring and summer seasons. In the summer the mean vapor pressure deficit was significantly different both in day and in night periods at the two stations, while in the spring, the difference was only significant during the night. This table also shows that the total difference between the two stations throughout the year was not significant.

From Table 17 it can be seen that only the differences of the maximum vapor pressure deficit of the spring and summer seasons between the two stations were significant, while the annual mean difference was not significant. From this it may be concluded that the maximum vapor pressure deficit between the two stations as a whole was not significantly different, although it showed some high deviation in the spring and summer seasons.

The mean weekly values for the mean relative humidity of the two stations averaged on a 24-hour basis are plotted in Figure 2. The highest mean weekly relative humidity during 24 hours was in the week of January 18 to January 24, 1937, for both stations, with a value of 96.16 percent for the station in the plantation, and a value of 95.55 percent for the station in the open area. The lowest mean weekly relative humidity during 24 hours was in the week of April 12 to April 18, 1937, with a value of 63.94 percent in the plantation and a value of 57.94 percent in the open area.

The mean weekly values for the mean vapor pressure deficit of the two stations during 24 hours are plotted in Figure 3. The highest mean weekly vapor pressure deficit during 24 hours occurred in the week of July 5 to 11, 1937, with a value of 8.62 mm. of mercury in the plantation and a value of 9.16 mm. in the open area. The lowest value in the plantation was 0.44 mm. in the week of December 28, 1936, to January 3, 1937, while that for the open area was 0.49 mm., the average for the week of December 7 to 13, 1936.

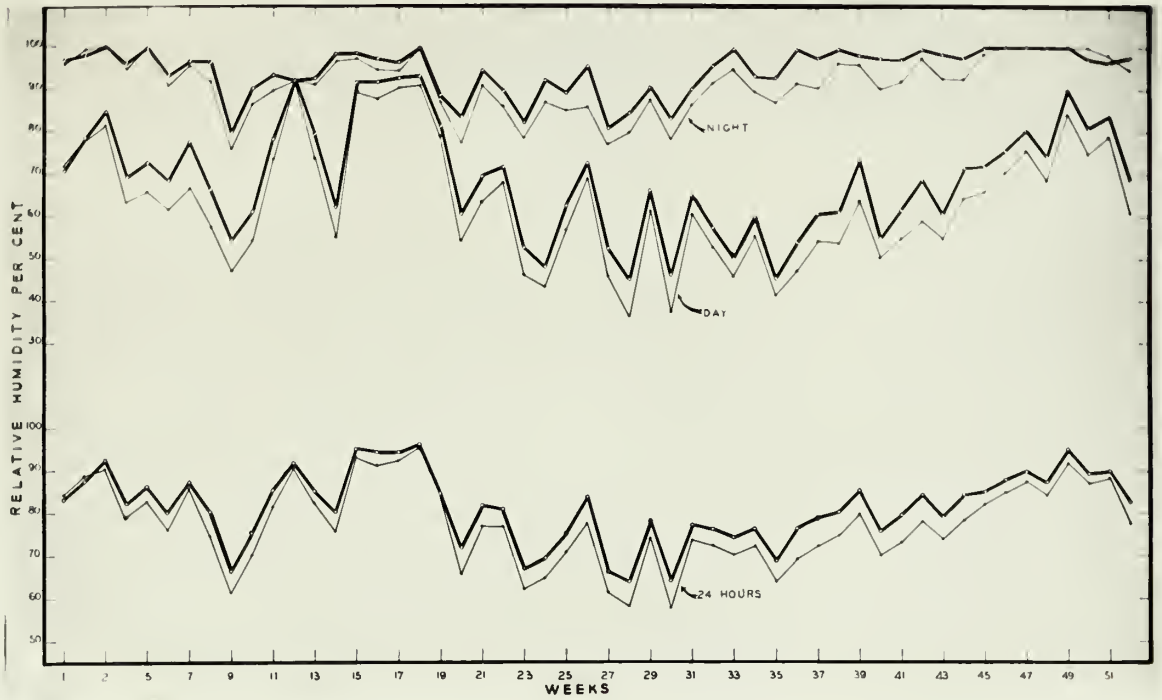

Figure 2. The weekly mean relative humidity at the two stations from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation, and the light lines represent the open area.

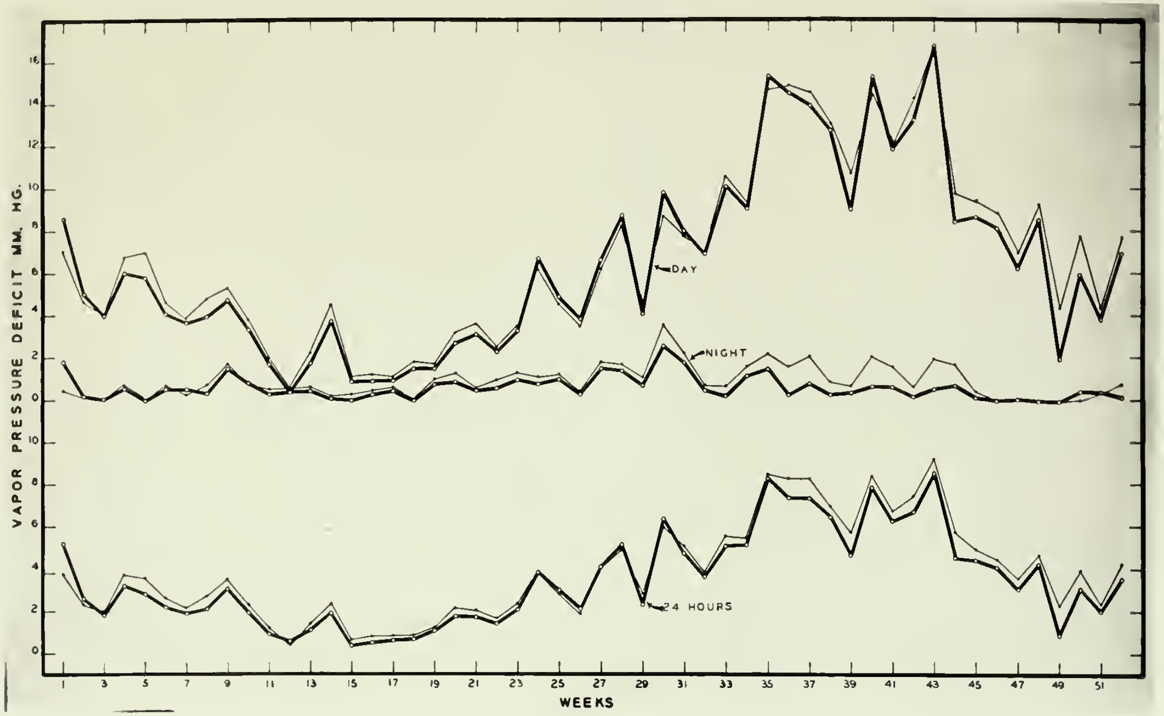

Figure 3. The weekly mean vapor pressure deficit at the two stations from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation and the light lines represent the open area.

The mean weekly values for the mean relative humidity during the day and night period for the two stations are plotted in Figure 2. The highest mean relative humidity in the day period was in the week of January 18 to 24, 1937, with a value of 92.33 percent for the plantation, and that of 91.10 percent for the open area. The lowest mean relative humidity during the day period was 44.38 percent for the plantation and 36.63 percent for the open area, both of which were in the week of March 29 to April 4, 1937.

The lowest mean relative humidity during the night period was in the week of November 16 to 22, 1936, with a value of 78.83 percent for the plantation and 75.95 percent for the open area.

The mean weekly values for the mean vapor pressure deficit during the day and night for the two stations are plotted in Figure 3. The highest vapor pressure deficit for the day was in the week of July 12 to 18, 1937. The average for that week was 16.64 mm. in the plantation and 16.47 mm. in the open area. The lowest values were in the week of December 7 to 13, 1936. The average for that week in the plantation was 0.44 mm., while in the open area it was 0.52 mm. The highest mean vapor pressure deficit during the night period was in the week of April 12 to 18, 1937. The average for that week in the stand was 2.59 mm. and that in the open area was 3.47 mm.

The mean weekly values for the minimum relative humidity for the two stations are plotted in Figure 4. The highest value for the mean weekly minimum relative humidity in the plantation was 82.43 percent, and that in the open area was 80.57 percent, both of which were in the week of January 18 to 24, 1937. The lowest values were 24.57 percent for the plantation and 20.32 percent for the open area, both of which were in the week of March 29 to April 4, 1937.

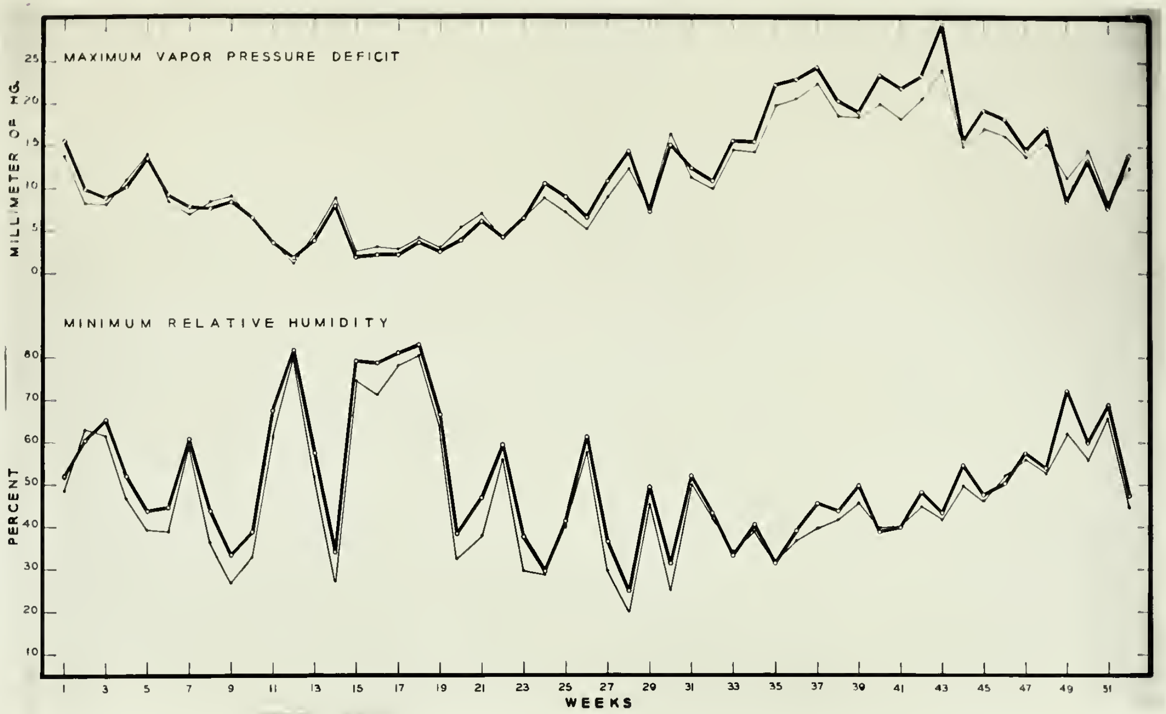

Figure 4. The weekly minimum relative humidity and the weekly maximum vapor pressure deficit at the two stations from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation and the light lines represent the open area.

The mean weekly values for the maximum vapor pressure deficit for the two stations are plotted in Figure 4. The highest value in the plantation was 29.28 mm. and that in the open area was 24.17 mm., both of which were in the week of July 19 to 25, 1937. The lowest values were 1.47 mm. for the plantation and 1.38 mm. for the open area; both are the average values for the week of December 7 to 13, 1937.

Precipitation:

The total seasonal and annual precipitation at the two stations is given in Table 18 in which are also shown the seasonal and annual differences between the two stations with their fiducial limits (ts). The analysis of variance of the data is given in Table 19. From the table of analysis of variance, it will be noticed that the rainfall in the four seasons of the year was not significantly different, and the difference in rainfall at the two stations was also not significant. As for the precipitation at the two stations in different seasons, only that in the summer season showed a difference high enough to exceed its fiducial limit. This significant difference in rainfall in the summer season does not mean that the quantity of the rain falling on these two areas was different, but it may mean that a significant quantity of rain was intercepted by the crown canopy of the plantation causing the difference between the amount of precipitation at the two places to be greater than the error of sampling.

The weekly amounts of rainfall throughout the year at the two stations are plotted in Figure 5. The highest amount of rainfall received was in the week of August 23 to 29, 1937, with a value of 6.07 inches for the plantation and 7.31 for the open area.

Air Movement:

The air movement was recorded in total number of miles traveled

Table 18. Total seasonal and annual precipitation in inches at the two stations.

	In the plantation	In the open area	In percent of the plantation value	Difference (Plantation - Open)	ts	
Autumn	11.71	10.83	92.5	0.88	2.37*	1.77**
Winter	14.18	13.51	95.3	0.67	2.37	1.77
Spring	8.68	8.35	96.2	0.33	2.37	1.77
Summer	19.19	23.29	121.4	- 4.10	2.37	1.77
Total	53.76	55.98	104.1	- 2.22	28.74*	15.11**

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*1 percent
**5 percent

Table 19. Analysis of variance of precipitation at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean square	Observed F
Both stations combined				
Between seasons	3	13.7939	4.5980	F = 1.71 P = 0.1640
Residual between weeks of the same season (Error 1)	48	129.3946	2.6957	
Total between weeks	51	143.1885		
Differences between stations				
Between station averages	1	0.0474	0.0474	F = 4.57 P = 0.6671
Station-season interaction	3	0.6503	0.2168	F = 7.23 P = 0.0000268
Residual between weeks of the same season (Error 2)	48	1.4420	0.0300	
Total	103	145.3282		

ts for between season totals = 23.77 (5 percent)[1]

ts for between station total of the same season = 2.37 (1 percent), 1.77 (5 percent)[2]

ts for between total of the two stations = 28.79 (1 percent, 15.11 (5 percent)[3]

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[1] s for total calculated from error 1, based on 48 degrees of freedom.

[2] s for total calculated from error 2, based on 48 degrees of freedom.

[3] s for total calculated from mean squares of season-station interaction based on 3 degrees of freedom.

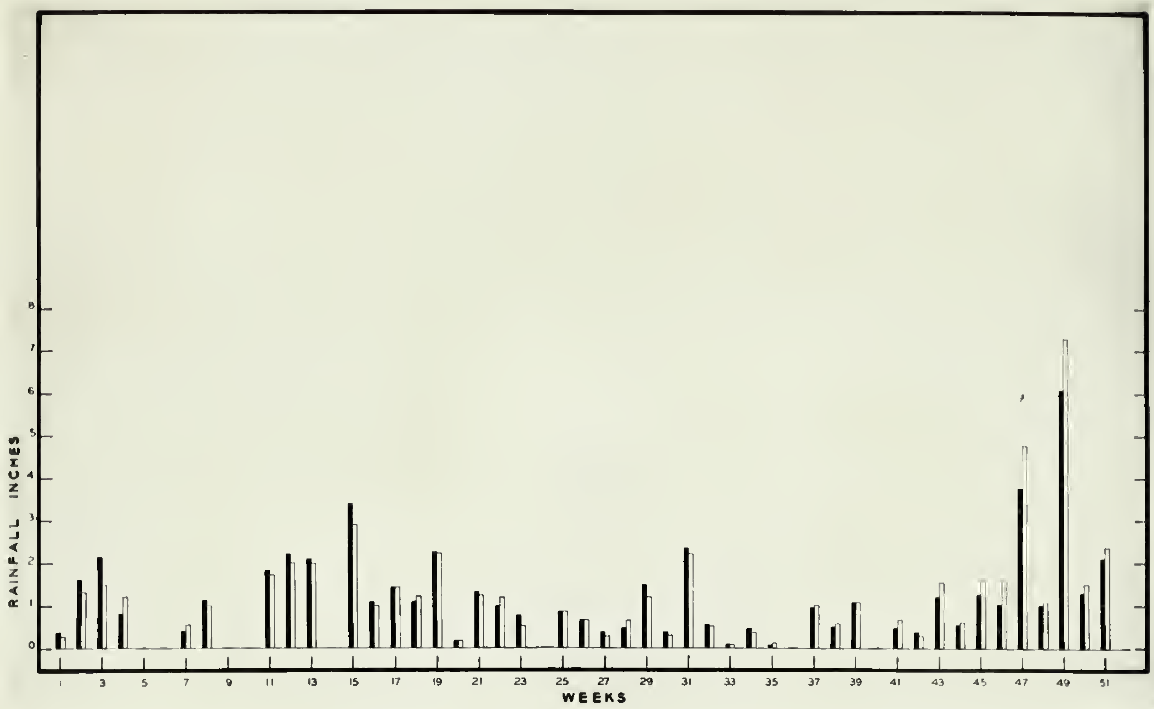

Figure 5. The weekly total of rainfall at the two stations from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The solid blocks represent the plantation and the blank blocks represent the open area.

[illegible]

by the wind in weekly intervals during the period of observation. The results of observation are summarized in Table 20. The analysis of variance of this data is given in Table 21. By looking at the data given in Table 20 it is very evident that wind velocity was greatly reduced in all seasons of the year in the plantation. The difference is so apparent that the conclusion can readily be drawn without referring to the results shown by analysis of variance as given in Table 21. By further examination of the data shown in Table 22, it will be found that the air movement in the plantation during the winter increased almost five times as much as that of the autumn, but the air movement in the open area during the same season only increased about one fifth as much. Another fact noticed in the same table is that the highest air movement in the plantation was in the spring, while that in the open area was in the winter. This fact may be explained by assuming that the hours of calm in the autumn and winter were about the same but the velocity of wind was very much increased during the winter. Since neither hourly nor daily observations on wind velocity were made, this explanation is only considered as tentative rather than as certain. The second fact, the discrepancy in air movement in the winter and spring seasons between the two stations, may be explained by statistical analysis. If the differences in air movement between these two stations are compared with their fiducial limits (ts), it is seen that both were lower than that value. The difference in air movement between winter and spring in the plantation was - 140.8 miles, and the ts values were 300.1 (1 percent) and 224.5 (5 percent). The difference between these two seasons in the open area was 141 miles which was also lower than the ts values. Since the difference between these two seasons at either station was not significant, the discrepancy in air movement during these seasons at the two stations

Table 20. Seasonal and annual air movement at the two stations expressed in total number of miles traveled by the wind. (Velocity is given in miles per hour, and pressure is given in pounds per square foot, calculated from the formula $P = 0.005 V^2$).

Season	In the plantation				In the open area		
	Total miles	In percent of open area	Average velocity	Average pressure	Total miles	Average velocity	Average pressure
Autumn	114.5	2.0	0.05	--	5646.9	2.59	0.036
Winter	506.8	7.9	0.23	--	6383.0	2.88	0.045
Spring	647.6	10.4	0.30	--	6242.0	2.86	0.043
Summer	278.7	6.4	0.13	--	4338.1	1.99	0.020
Total for year	1547.6	6.8	0.18	--	22610.0	2.59	0.036

Table 21. Analysis of variance of the air movement.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between seasons	3	136426.7292	45475.5764	F = 0.32 P = 0.00005
Residual between weeks of the same season (Error 1)	48	234293.2262	4881.1098	
Total between weeks	51	370719.9554		
Differences between stations				
Between station averages	1	4265622.0554	4265622.0554	F = 37.79 P = 0.0012
Season-station interaction	3	77193.9415	25731.3138	F = 3.78 P = 0.0168
Residual between weeks of the same season (Error 2)	48	326854.4595	6809.4679	
Total	103	5040490.4154		

ts for between season sums = 1349.2[1]

ts for between station sums = 2211.5[2]

ts for between station sums in the same season = 1105.8[3]

ts for between season sums of the same station = 300.1 (1 percent), 224.5 (5 percent)[1]

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[1] *s* for sums calculated from error 1, based on 48 degrees of freedom.

[2] *s* for sums calculated from mean square of season-station interaction, based on 3 degrees of freedom.

[3] *s* for sums calculated from error 2, based on 48 degrees of freedom.

Table 22. Seasonal and annual average number of grams of water evaporated near the surface of the ground and at a height of six feet at the two stations.

Season	In the plantation					In the open area			
	Near surface of ground	In percent of open area values	At height of 6 feet	In percent of open area values	Average of 2 positions	Near surface of ground	In percent of 6-ft. height values	At height of 6 feet	Average of 2 positions
Autumn	32.18	59.9	32.51	32.5	32.34	53.73	53.64	100.16	76.94
Winter	13.36	33.1	20.33	19.2	16.84	40.41	38.10	106.07	73.24
Spring	50.43	32.2	78.64	24.0	64.53	156.47	47.75	327.68	242.08
Summer	36.02	27.3	57.38	19.9	46.70	132.08	45.84	288.14	210.11
Mean of year	33.00	34.5	47.21	23.0	40.10	95.67	46.55	205.51	150.59

also may be said to be not significant.

The total wind movement for weekly periods throughout the year at the two stations is plotted in Figure 6, in which it will be seen that the highest value for air movement was in the week of January 25 to 31, 1937 with a value of 746.6 miles in the open area and 83.4 miles in the plantation.

Evaporation:

A summary of the weekly observations on evaporation of two positions at the two stations is shown in Table 22 in which are given the seasonal and annual average number of grams of water evaporated in one week. This table shows very clearly that there was a distinct difference in evaporation rate at the two stations throughout the year, both close to the surface of the ground and in the free atmosphere. That there is a definite difference in evaporation in the two positions in the open area is also evident from Table 22. The evaporation at the height of six feet was undoubtedly higher than that close to the ground, although the amount varied to some extent with the season of the year. In the plantation, the evaporation at the two positions did not differ very much, the rate was almost the same in the autumn, and was also very close in the winter. Analysis of variance of the data on evaporation is given in Table 23.

In Table 23, it is shown that the differences in the four seasons, between the two stations, and at the two positions were significant. Detailed comparisons of the differences between the two stations is shown in Table 24, in which the seasonal and annual differences in evaporation between the two stations in the same position, and the differences between the two positions at the same station, together with their fiducial limits, are given. From this table it will be noticed that in the autumn and winter

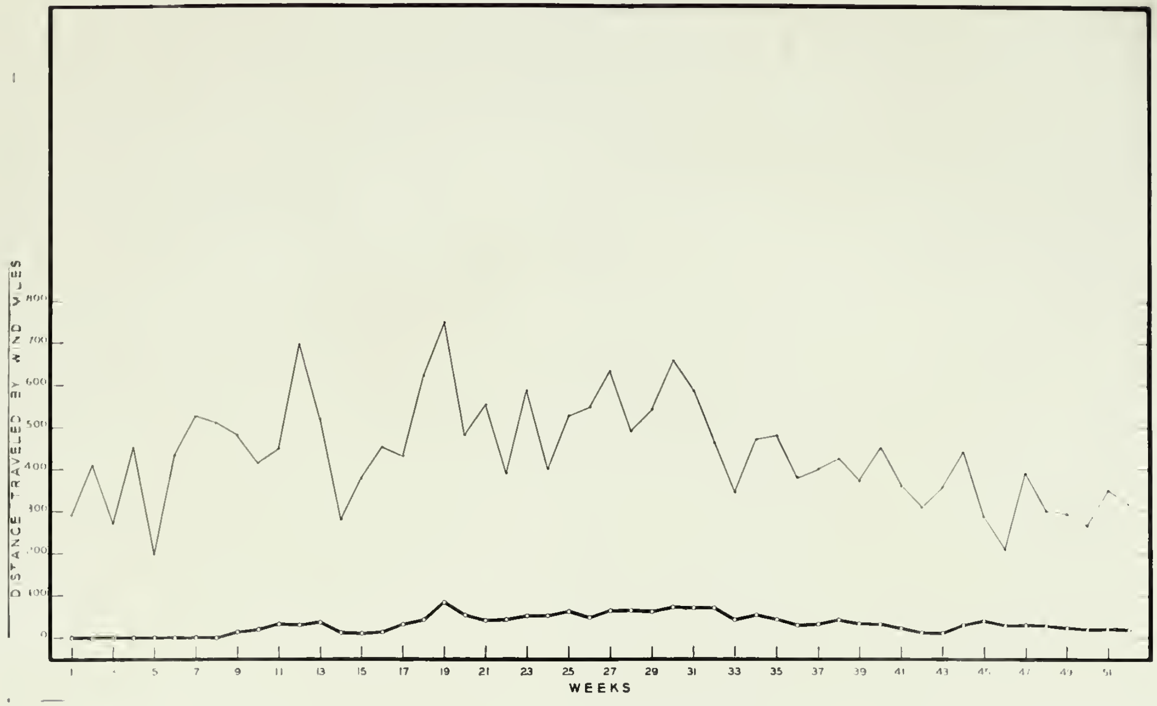

Figure 6. The total wind movement at weekly periods at the two stations, from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation and the light lines represent the open area.

Table 23. Analysis of variance of the weekly rate of evporation at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined with the two positions combined				
Between seasons	3	449253.4550	149751.1517	F = 34.92 P < 0.0000001
Residual between weeks of the same season (Error 1)	48	205869.4249	4288.9464	
Total between weeks	51	655122.8799		
Differences between two stations with the two positions combined				
Between station averages	1	634780.5192	634780.5192	F = 10.06 P = 0.0505
Station-season interaction	3	189333.7038	63111.2346	F = 41.51 P < 0.0000001
Residual between weeks of the same season (Error 2)	48	72981.2688	1520.4431	
Total between weeks	103	1552218.3717		
Differences between two positions at separate stations				
Between average of the two positions	1	200071.5621	200071.5621	F = 24.34 P = 0.0160
Season-position interaction	3	55735.5238	18578.5079	F = 2.26 P = 0.2640
Station-position interaction	1	118870.0032	118870.0032	F = 14.46 P = 0.0314
Season-station-position interaction	3	24660.8484	8220.2828	F = 29.93 P < 0.0000001
Remainder (Error 3)	96	26370.2142	274.6897	
Total	207	1977926.5234		

Table 23. (Continued)

ts for between seasonal means = 34.40 (1 percent), 25.80 (5 percent)[1]

ts for between station means = 110.73 (5 percent)[2]

ts for between station means of the same position = 20.52 (1 percent)[3]

ts for between station means of the same position in the same season = 41.02 (1 percent), 30.69 (5 percent)[3]

ts for between position means at the same station = 103.85 (1 percent), 56.58 (5 percent)[4]

ts for between position means at the same station in the same season = 17.08 (1 percent), 12.90 (5 percent)[4]

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[1] s calculated from error 1, based on 48 degrees of freedom.

[2] s calculated from mean square for season-station interaction, based on 3 degrees of freedom.

[3] s calculated from error 2, based on 48 degrees of freedom.

[4] s calculated from mean squares for season-station-position interaction, based on 3 degrees of freedom.

[5] s calculated from error 3, based on 96 degrees of freedom.

Table 24. Differences in seasonal and annual average amount of evaporation in grams at the two stations.

Season	Differences (Open - Plantation)				Differences (Six-feet - Ground)			
	Near surface of ground	At height of six feet	ts		In the stand	In the open area	ts	
Autumn	21.55	67.65	41.02*	30.69**	0.34	46.43	17.08*	12.90**
Winter	27.04	85.74	41.02	30.69	6.97	65.66	17.08	12.90
Spring	106.04	249.04	41.02	30.69	28.21	171.21	17.08	12.90
Summer	96.06	230.76	41.02	30.69	21.36	156.06	17.08	12.90
Mean of year	62.68	158.30	20.52		14.22	109.84	103.85*	56.58**

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*1 percent
**5 percent

seasons, the differences in rate of evaporation near the ground at the two stations were not significant, but in the spring and summer seasons, and in the year as a whole, the differences were significant. The differences in evaporation between the two stations at the height of six feet were significant whether it was during each season or throughout the year. The differences in evaporation between the two positions at the same station were also compared in the same table. It showed that in the plantation only in the spring and summer seasons were the differences in evaporation between the two positions significant, while in the open area there was a significant annual difference between these two positions, as well as in each season of the year.

The weekly amounts of evaporation in grams of water at the two positions at the two stations are plotted in Figure 7. The highest amount of evaporation at the height of six feet was 440.0 grams in the open area, and 106.7 grams in the plantation, both of which were in the week of June 7 to 13, 1937. The highest amount of evaporation close to the surface of the ground was 231.5 grams in the open area, which was for the week of June 21 to 27, 1937, while the highest value for the same in the stand was 70.6 grams, in the week of May 17 to 23, 1937.

Regression of Evaporation on Other Microclimatic Factors:

It has already been shown in the section on evaporation that the evaporation rate at the two stations was significantly different. Evaporation, however, is affected by many factors, such as air temperature, relative humidity, vapor pressure deficit, wind velocity, and precipitation. Since all such factors are modified to some extent in the plantation, as shown in the foregoing sections, it is very desirable to ascertain whether there is any quantitative relationship between the modification of such

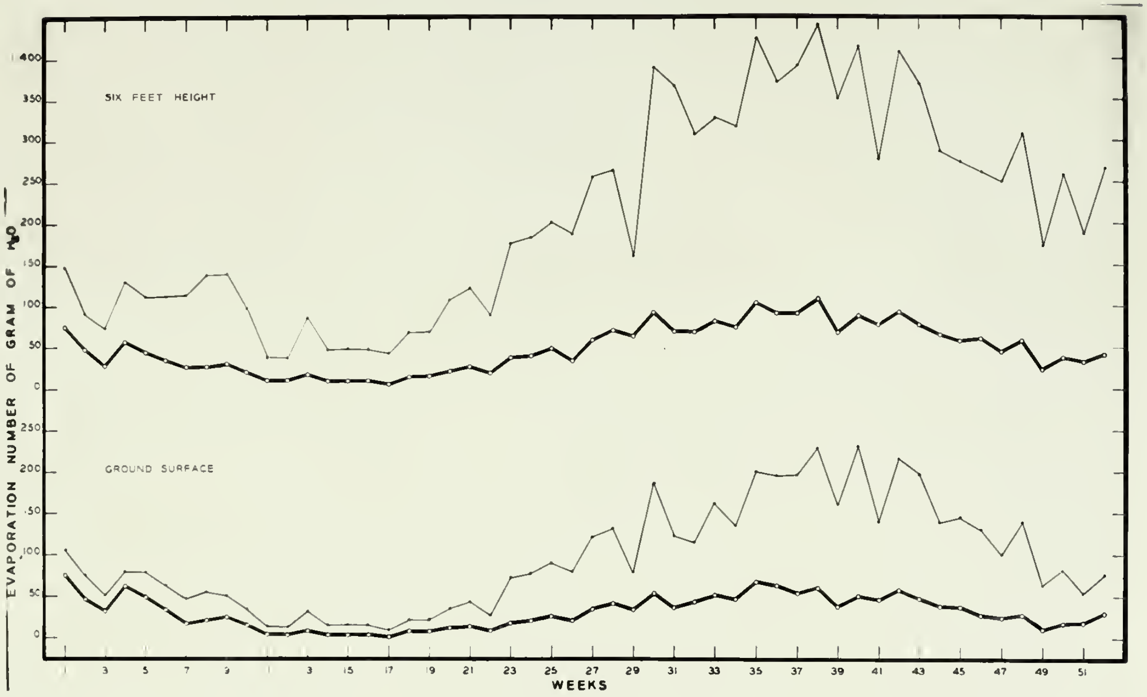

Figure 7. Weekly evaporation at two heights at the two stations, from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation and the light lines represent the open area.

[illegible]

microclimatic factors and the change in amount of evaporation in the plantation. In order to clarify this quantitative relationship, the regression of evaporation on the other microclimatic factors for the same season was calculated. Because the calculating process is rather complicated some explanation of the method is needed before the results of the calculation are to be considered.

The process used is known in statistics as multiple regression because there was only one dependent variable, but several independent variables. The dependent variable used here was the weekly amount of water evaporated as a deviation from expectation at the season and the independent variables were the observed weekly records of the following microclimatic factors, also as deviations from expectations at the season: (1) mean weekly air temperature, (2) mean weekly maximum air temperature, (3) mean weekly relative humidity, (4) mean weekly minimum relative humidity, (5) mean weekly vapor pressure deficit, (6) mean weekly maximum vapor pressure deficit, (7) total distance traveled by wind in one week, and (8) amount of rainfall in one week. The present case is complicated by the fact that seasonal trends must be eliminated in all the variables used here, both dependent and independent. In other words, all the variables were curvilinear functions of time and the time trends were eliminated by the method of fitting polynominals perfected by Fisher (1936). The residuals of the variables from their trend values were then used for calculating the regression of the amount of evaporation on other microclimatic factors.

Because there were two series of observations on evaporation at each station, namely, that near the surface of the ground and that at a height of six feet, the calculation of regression was complicated by the fact that there were two series of dependent variables instead of one as is

usually the case. Therefore, two regressions had to be tried first in order to determine whether the regressions of the two series of observations on the other microclimatic factors were the same or different. These two regressions were the regression of the sum of evaporation at the two positions, and that of the difference of evaporation at the two positions. If the regressions of both the difference and the sum of the two positions are not significant, it means that there is no proven relationship between evaporation and the other microclimatic factors. If, however, the regression of the difference is significant, while the regression of the sum is either significant or not, it means that the regressions of the two positions are different. If such is the case, it means that the amount of difference in evaporation between the two positions was determined by the other microclimatic factors. To express it in another way, it shows that the evaporation rate in the two positions was affected by the other factors in such a decidedly different manner that their differences became a definite quantity which was a fixed function of the other microclimatic factors. A third case still remains; that is, in which the regression of the sum is significant but that of the difference is not. In this case, it means that if the regression of evaporation of the two positions were the same, it may be said that the evaporation rates of the two positions had no relation to one another so far as interaction with the other microclimatic factors is concerned.

The analysis of variance of the results of the calculation of regression is given in Tables 25 to 28. The numerical values for all the regression coefficients with their standard errors are given in Table 29. It is shown in Table 25 that the regression of the differences in evaporation between the two positions in the plantation is not significant; only the regression of the sum of evaporation in the plantation was significant

Table 25. Analysis of variance of regression for the differences of evaporation on other microclimatic factors in the plantation.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Regression	8	309.5638	38.6954	F = 1.86 P = 0.10
Independent of regression	40	832.7601	20.8190	
Total	48	1142.3239		

Table 26. Analysis of variance of regression for the sums of evaporation on the other microclimatic factors in the plantation.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Regression	8	14341.1045	1792.6381	$F = 11.77$ $P < 0.0000001$
Independent of regression	40	6092.7606	152.3190	
Total	48	20433.8651		

Table 27. Analysis of variance of regression for the differences of evaporation on other micromiclimatic factors in the open area.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Regression	8	28870.0546	3608.7568	F = 6.89 P = 0.0000112
Independent of regression	40	20960.6482	524.0162	
Total	48	49830.7028		

Table 28. Analysis of variance of regression for the sum of evaporation on the other microclimatic factors in the open area.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Regression	8	208782.8187	26097.8523	F = 14.01 P < 0.0000001
Independent of regression	40	74502.4313	1862.5608	
Total	48	283285.2500		

Table 29. The regression coefficients of the two series of observations.

(1) For the differences of evaporation in the plantation:

Independent variables	Regression Coefficients	Standard Error
Mean air temperature (X_1)	0.14576 (= b_1)	0.38985
Mean maximum air temperature (X_2)	0.28472 (= b_2)	0.39751
Mean relative humidity (X_3)	- 0.11711 (= b_3)	0.37643
Mean minimum relative humidity (X_4)	- 0.03913 (= b_4)	0.17900
Mean vapor pressure deficit (X_5)	2.70283 (= b_5)	2.16058
Mean maximum vapor pressure deficit (X_6)	- 0.83330 (= b_6)	0.79562
Total distance traveled by wind at weekly intervals (X_7)	0.01282 (= b_7)	0.06406
Total rainfall at weekly intervals (X_8)	0.14016 (= b_8)	0.89326

(2) For the sums of evaporations in the plantation:

Independent variables	Regression coefficients	Standard error
Mean air temperature (X_1)	- 0.57470 (= b_1)	1.05448
Mean maximum air temperature (X_2)	1.46916 (= b_2)	1.07522
Mean relative humidity (X_3)	0.78539 (= b_3)	1.01820
Mean minimum relative humidity (X_4)	- 0.47719 (= b_4)	0.48417
Mean vapor pressure deficit (X_5)	24.13495 (= b_5)	5.84409
Mean maximum vapor pressure deficit (X_6)	- 6.29164 (= b_6)	2.15204
Total distance traveled by wind at weekly intervals (X_7)	0.27302 (= b_7)	0.17328
Total rainfall at weekly intervals (X_8)	- 3.28113 (= b_8)	2.41615

Table 29. (Continued)

(3) For the differences of evaporation in the open area:

Independent variables	Regression coefficients	Standard error
Mean air temperature (X_1)	-1.38858 ($= b_1$)	3.06791
Mean maximum air temperature (X_2)	4.90721 ($= b_2$)	2.35850
Mean relative humidity (X_3)	-2.27587 ($= b_3$)	1.92860
Mean minimum relative humidity (X_4)	0.16429 ($= b_4$)	1.05896
Mean vapor pressure deficit (X_5)	15.64605 ($= b_5$)	11.19000
Mean maximum vapor pressure deficit (X_6)	-8.04661 ($= b_6$)	5.29158
Total distance traveled by wind at weekly intervals (X_7)	0.09441 ($= b_7$)	0.04441
Total rainfall at weekly intervals (X_8)	-1.29757 ($= b_8$)	3.80089

(4) For the sum of evaporation in the open area:

Independent variables	Regression coefficients	Standard error
Mean air temperature (X_1)	-1.15977 ($= b_1$)	5.78395
Mean maximum air temperature (X_2)	5.16732 ($= b_2$)	4.44651
Mean relative humidity (X_3)	-4.32285 ($= b_3$)	3.63601
Mean minimum relative humidity (X_4)	1.27342 ($= b_4$)	1.99646
Mean vapor pressure deficit (X_5)	25.54347 ($= b_5$)	21.09663
Mean maximum vapor pressure deficit (X_6)	1.58796 ($= b_6$)	9.97626
Total distance traveled by wind at weekly intervals (X_7)	0.20206 ($= b_7$)	0.08373
Total rainfall at weekly intervals (X_8)	-8.66975 ($= b_8$)	7.16585

(Table 26). In the open area, however, the regression of both the sum and the difference was significant. (Tables 27 and 28).

From the results of analysis of variance it was decided that there was only one regression equation for evaporation in the plantation, but two regression equations for evaporation in the open area; one for that near the ground surface, and one for that at a height of six feet. These equations are given below:

(1) Regression equation for evaporation rate on the other microclimatic factors in the plantation:

$$Y1 = -0.28735X_1 + 0.73458X_2 + 0.39270X_3 - 0.23859X_4 + 12.06748X_5 - 3.14582X_6 + 0.13651X_7 - 1.64056X_8$$

In which Y_1 = the estimated evaporation rate independent of seasonal effect

X_1 = the value of mean air temperature

X_2 = the value of mean maximum air temperature

X_3 = the value of mean relative humidity

X_4 = the value of mean minimum relative humidity

X_5 = the value of mean vapor pressure deficit

X_6 = the value of mean maximum vapor pressure deficit

X_7 = the value of total wind movement at weekly periods

X_8 = the value of amount of rainfall

Note: the regression coefficients in equation (1) were obtained by dividing by 2 those for the sum of two positions.

All the values for X's are residuals from the time trend.

(2) Regression equation for the evaporation rate near the surface of the ground in the open area, on other microclimatic factors:

$$Y_2 = 0.11441X'_1 + 0.13015X'_2 - 2.0234X'_3 + 0.55475X'_4 + 4.94871X'_5 + 4.81728X'_1 + 0.05382X' - 3.68609X'$$

in which Y_2 is the estimated evaporation rate independent of the seasonal

effect, and the X's have the same indications as in equation (1) except that they are the residuals from the data observed in the open area.

Note: The regression coefficients for equation (2) were obtained by dividing by 2 the differences between those for sum and those for the difference of evaporation of the two positions.

$$(3)\ Y_3 = -\ 1.27147X' + 5.03726X'_2 - 3.29936X'_3 + 0.71886X'_4 + 20.59448X'_5 - 3.22932X' + 0.14823X' - 4.98366X'$$

in which Y_3 is the estimated evaporation rate independent of the seasonal effect at the height of six feet in the open area. All the X's have the same indications as in equation (2).

Note: The regression coefficients used in equation (3) were obtained by dividing by 2 the sum of those for the sum and those for the difference of evaporation.

In order to test the significance of the regression coefficients given in Table 29, the so-called "c" factors or multipliers were calculated according to the method devised by Fisher (1936). All the "c" multipliers calculated from the two series of independent variables are given in Table 30. From such "c" multipliers, the standard error for each regression coefficient can be determined by using the following formula:

$$S_b = s/\overline{c}$$

in which S_b is the standard error for the regression coefficient, s is the standard error for the total regression, and c the corresponding "c" multiplier for the regression coefficient. To test the significance of the regression coefficient, the ratio with its standard error (b/S_b) is calculated, and compared with the value in the table of t, entereing with the same number of degrees of freedom as that used for the standard error for the total regression (s). The results of this test are also given in Table 30, in which it will be seen that in the plantation the only two significant coefficients were those for the mean vapor pressure deficit and for the

Table 30. "c" multipliers and the test of significance of the regression coefficients.

(1) For the regression coefficients of the sum of evaporation in the plantation.

For b_1, $c_{11} = 0.007300790955$ $\qquad b_1/s\sqrt{c_{11}} = 0.545$

For b_2, $c_{22} = 0.007589830024$ $\qquad b_2/s\sqrt{c_{22}} = 1.366$

For b_3, $c_{33} = 0.006806080329$ $\qquad b_3/s\sqrt{c_{33}} = 0.771$

For b_4, $c_{44} = 0.001539102028$ $\qquad b_4/d\sqrt{c_{44}} = 0.985$

For b_5, $c_{55} = 0.224222923773$ $\qquad b_5/s\sqrt{c_{55}} = 4.130$*

For b_6, $c_{66} = 0.030404228361$ $\qquad b_6/s\sqrt{c_{66}} = 2.924$*

For b_7, $c_{77} = 0.000197231809$ $\qquad b_7/s\sqrt{c_{77}} = 1.576$

For b_8, $c_{88} = 0.038326440477$ $\qquad b_8/s\sqrt{c_{88}} = 1.386$

($s = 12.3418$)

(2) For the regression coefficients of the difference and the sum of evaporation in the open area.

For b_1, $c_{11} = 0.010706118600$ $\qquad b_1/s\sqrt{c_{11}} = 2.081$ (for difference)*

$b_1/s\sqrt{c_{11}} = 0.201$ (for sum)

For b_2, $c_{22} = 0.010614789664$ $\qquad b_2/s\sqrt{c_{22}} = 2.081$ (for difference)*

$b_2/s\sqrt{c_{22}} = 1.162$ (for sum)

For b_3, $c_{33} = 0.007098500138$ $\qquad b_3/s\sqrt{c_{33}} = 1.180$ (for difference)

$b_3/s\sqrt{c_{33}} = 1.189$ (for sum)

For b_4, $c_{44} = 0.002139811960$ $\qquad b_4/s\sqrt{c_{44}} = 0.155$ (for difference)

$b_4/s\sqrt{c_{44}} = 0.638$ (for sum)

For b_5, $c_{55} = 0.238958787341$ $\qquad b_5/s\sqrt{c_{55}} = 1.398$ (for difference)

$b_5/s\sqrt{c_{55}} = 1.211$ (for sum)

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*Significant; value of t entered in the table = 2.704 (1 percent), 2.021 (5 percent), for 40 degrees of freedom.

Table 30. (Continued)

For b_6, $c_{66} = 0.053434070766$ $b_6/s\sqrt{c_{66}} = 1.521$ (for difference)

$b_6/s\sqrt{c_{66}} = 0.159$ (for sum)

For b_7, $c_{77} = 0.000003780130$ $b_7/s\sqrt{c_{77}} = 2.126$ (for difference)*

$b_7/s\sqrt{c_{77}} = 2.413$ (for sum)*

For b_8, $c_{88} = 0.027570695550$ $b_8/s\sqrt{c_{88}} = 0.341$ (for difference)

$b_8/s\sqrt{c_{88}} = 1.210$ (for sum)

(s for the difference = 22.8914,
s for the sum = 43.1574)

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*Significant; value of t entered in the table = 2.704 (1 percent), 2.021 (5 percent), for 40 degrees of freedom.

mean maximum vapor pressure deficit. In the open area the coefficients for the mean air temperature and for the total air movement per week were significant for the difference in evaporation, while that for wind movement alone was significant for the sum of evaporation of the two positions.

Soil Temperature:

The observations on soil temperatures, including weekly mean, mean maximum, and mean minimum temperatures, at the two depths for the two stations, are summarized in Tables 31, 34, and 37. In table 31 the seasonal and annual averages for the mean weekly soil temperatures at the two depths at the two stations are given. From this table it will be seen that the temperatures at these two stations, just beneath the soil surface and at the depth of six inches, showed some distinct difference only in the spring and summer seasons. The temperatures for the autumn and winter seasons at both depths for these two stations did not differ much. Although the surface soil temperatures were always higher than the temperature at six inches, throughout the year at either one of the two stations, the differences are not great. The analysis of variance of the data is given in Table 32. The results showed that the differences in temperature between seasons and between depths were significant, but that between the two stations was not significant when the temperatures of the two depths for each station were pooled together.

The seasonal and annual differences at the two depths between the two stations, and those between the two depths of the same station, are given in Table 33 together with their fiducial limits (ts). From this table it will be seen that all the seasonal differences between the two stations were significant at two depths, except that of the surface temperature in

Table 31. Seasonal and annual averages of mean weekly soil temperatures in degrees F. at two depths at the two stations.

Season	In the plantation			In the open area		
	Soil surface	At 6-inch depth	Average	Soil surface	At 6-inch depth	Average
Autumn	53.17	52.10	52.64	53.88	53.80	53.84
Winter	43.32	41.77	42.54	44.22	43.18	43.70
Spring	60.70	58.47	59.58	65.31	63.35	64.33
Summer	72.89	71.84	72.36	78.28	77.66	77.96
Mean of year	57.52	56.04	56.78	60.42	59.50	59.96

Table 32. Analysis of variance of the mean weekly soil temperatures.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	28800.1455	9600.0485	F = 33.07 P < 0.0000001
Residual between weeks of the same season (Error 1)	48	13935.8505	290.3302	
Total between weeks	51	42735.9960		
Differences between two stations with the two depths combined				
Between station averages	1	525.2551	525.2551	F = 7.43 P = 0.0732
Station-season interaction	3	212.2018	70.7339	F = 34.43 P < 0.0000001
Residual between weeks of the same season (Error 2)	48	98.6046	2.0534	
Total between weeks	103	43572.0575		
Differences between two depths at separate stations				
Between averages at two depths	1	74.9784	74.9784	F = 12.96 P = 0.0374
Depth-season interaction	3	17.3505	5.7835	F = 41.79 P < 0.0000001
Depth-station interaction	1	3.9595	3.9595	F = 28.61 P = 0.0000006
Depth-station-season interaction	3	0.1788	0.0596	F = 2.32 P = 0.8085
Remainder (Error 3)	96	13.2899	0.1384	
Total	207	43681.8146		

Table 32. (Continued)

ts for between seasonal means = 8.95[1]

ts for between station means = 3.71 (5 percent)[2]

ts for between station means of the same position = 0.75 (1 percent)[3]

ts for between station means of the same position in the same season = 1.51 (1 percent), 1.13 (5 percent)[3]

ts for between position means = 1.06 (5 percent)[4]

ts for between position means of the same station = 0.19[5]

ts for between position means of the same station in the same season = 0.37 (1 percent), 0.28 (5 percent)[5]

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[1] s calculated from error 1, based on 3 degrees of freedom.

[2] s calculated from means for season-station interaction, based on 3 degrees of freedom.

[3] s calculated from error 2, based on 48 degrees of freedom.

[4] s calculated from mean square for season-depth interaction, based on 3 degrees of freedom.

[5] s calculated from error 3, based on 96 degrees of freedom.

Table 33. Differences in seasonal and annual averages of soil temperatures in degrees F. at the two stations.

Season	Differences (Open - Plantation)				Differences (Surface - 6 inches)			
	Soil surface	At 6-inch depth	ts		In the plantation	In the open	ts	
Autumn	0.71	1.70	1.51*	1.13**	1.07	0.08	0.37*	0.28**
Winter	0.90	1.41	1.51	1.13	1.55	1.04	0.37	0.28
Spring	4.61	4.88	1.51	1.13	2.23	1.96	0.37	0.28
Summer	5.39	5.82	1.51	1.13	1.05	0.62	0.37	0.28
Mean of year	2.90	3.46	0.75		1.48	0.92	0.19	

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*1 percent
**5 percent

Table 34. Seasonal and annual averages of the mean maximum soil temperatures in degrees F. at two depths at the two stations.

	In the plantation			In the open area		
	Soil surface	At 6-inch depth	Average	Soil surface	At 6-inch depth	Average
Autumn	57.51	54.62	56.07	61.76	57.33	59.54
Winter	46.90	44.01	45.46	51.35	46.90	49.12
Spring	67.42	62.55	64.98	77.41	69.18	73.29
Summer	78.30	75.06	76.68	87.35	82.16	84.75
Mean of year	62.53	50.06	60.80	69.46	63.89	66.68

Table 35. Analysis of variance of the mean weekly maximum soil temperatures.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	32400.5173	10800.1724	F = 31.62 P < 0.0000001
Between weeks of the same season (Error 1)	48	16394.3539	341.5490	
Total between weeks	51	48794.8712		
Differences between two stations with two depths combined				
Between station averages	1	1797.6924	1797.6924	F = 19.39 P = 0.0207
Station-season interaction	3	278.1010	92.7003	F = 23.32 P < 0.0000001
Residual between weeks of the same season (Error 2)	48	190.7846	3.9747	
Total between weeks	103	51061.4492		
Differences between the two depths at separate stations				
Between averages at two depths	1	1062.6068	1062.6068	F = 43.10 P = 0.008
Depth-season interaction	3	73.9635	24.6545	F = 23.92 P < 0.0000001
Depth-station interaction	1	57.2775	57.2775	F = 55.57 P < 0.0000001
Depth-station-season interaction	3	7.2775	2.4258	F = 2.35 P = 0.0718
Remainder (Error 3)	96	98.9502	1.0307	
Total	207	52361.2147		

Table 35. (Continued)

ts for between season means = 9.71[1]

ts for between station means = 4.25 (5 percent)[2]

ts for between station means of same depth = 1.04[3]

ts for between station means of the same depth in the same season = 2.09[3]

ts for between depths means = 1.81[4]

ts for between depth means of the same station = 0.52[5]

ts for between depth means of the same station in the same season = 1.05[5]

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[1] s calculated from error 1, based on 3 degrees of freedom.

[2] s calculated from mean squares for season-station interaction, based on 3 degrees of freedom.

[3] s calculated from error 2, based on 48 degrees of freedom.

[4] s calculated from mean squares for depth-season interaction, based on 3 degrees of freedom.

[5] s calculated from error 3, based on 96 degrees of freedom.

Table 36. Differences in seasonal and annual averages of the mean weekly maximum soil temperatures in degrees F. between the two stations, and between the two depths of the same station.

Season	Differences (Open - Plantation)			Differences (Surface - 6 inches)		
	Soil Surface	At 6-inch depth	ts	In the Plantation	In the open	ts
Autumn	4.25	2.71	2.09	2.89	4.43	1.05
Winter	4.45	2.89	2.09	2.89	4.45	1.05
Spring	9.99	6.63	2.09	4.87	8.23	1.05
Summer	9.05	7.10	2.09	3.24	5.19	1.05
Mean of year	6.93	4.83	1.04	3.47	5.57	0.52

Table 37. Seasonal and annual averages of the mean weekly minimum soil temperatures in degrees F. at two depths at the two stations.

Season	In the plantation			In the open area		
	Soil surface	At 6-inch depth	Average	Soil surface	At 6-inch depth	Average
Autumn	49.53	49.64	49.59	48.06	50.27	49.17
Winter	40.17	39.31	39.74	38.72	39.63	39.18
Spring	55.03	54.77	54.90	56.28	57.74	57.01
Summer	69.06	69.17	69.12	72.02	73.43	72.73
Mean of year	53.45	53.22	53.34	53.77	55.27	54.52

the autumn. The differences in temperature of the two depths at each station were all significant except that of the open area in the autumn season. From the same table it can also be noticed that the seasonal differences of temperature at the 6-inch depth between the two stations were always higher than that at the surface, and in the plantation the seasonal differences between the two depths were always higher than that in the open area.

The seasonal and annual average values for the mean weekly maximum soil temperatures are given in Table 34. From this table it is very evident that the maximum soil temperatures in the open area were considerably higher than the same in the plantation. The maximum surface temperature was also much higher than that at the depth of 6 inches. The analysis of variance of the data is given in Table 35, which shows that the differences between seasons, between stations, and between depths were all significant. A detailed comparison of the temperature differences between the two stations and between the two depths at the same station together with their fiducial limits (ts) are given in Table 36. It is evident from Table 36 that all the differences between the two stations, and between the two depths at the same station, were significant. This proves definitely that the maximum soil temperatures in the open area either at the soil surface or at a depth of 6 inches are higher than in the plantation, and also proves that the maximum surface soil temperatures, no matter whether in the open or in the plantation, were definitely higher than those at a depth of 6 inches. In comparing differences in maximum temperatures between the two stations, they were found to be much higher at the soil surface than at the depth of 6 inches. The differences in the maximum temperatures between the two depths were much greater in the open area than in the plantation, while the differences in

the mean soil temperatures were greater in the plantation than in the open area.

The seasonal and annual average values for the mean weekly minimum soil temperatures are given in Table 37. The differences between the two stations and between the two depths were very close. The analysis of variance of this data is given in Table 38 which shows that the only significant difference is that due to seasonal effect. The detailed comparisons are given in Table 39.

From Table 39 it will be seen that in the autumn and winter the surface minimum temperature in the plantation was higher than that in the open area, while in the spring and summer it was lower in the plantation than in the open area. All the seasonal differences in surface soil temperature between the two stations were significant, although the annual difference for the same was not. Contrary to this fact, at the depth of 6 inches the minimum temperature in the plantation was always lower than in the open area in any season of the year, although only the spring and summer showed a significant difference. As a general conclusion it may be said that in the spring and summer, the minimum soil temperatures in the plantation were lower than in the open area, either near the soil surface or at the depth of 6 inches, while in the autumn and winter the surface minima are higher in the plantation; but the difference between the two stations at the depth of 6 inches are not significant.

Another fact revealed in Table 39 is that in the plantation there were no significant differences between the minimum temperatures of the soil surface and those at the depth of 6 inches except in the winter when the minimum surface temperature was higher. In the open area the seasonal differences between the two depths were significant, and the surface minima were much lower than those at a depth of 6 inches.

Table 38. Analysis of variance of the mean weekly minimum soil temperatures at the two stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Both stations combined				
Between season averages	3	27191.7753	9063.9251	F = 33.00 P < 0.0000001
Residual between weeks of the same season (Error 1)	48	13184.3621	274.6742	
Total between weeks	51	40376.1374		
Differences between two stations with two depths combined				
Between station averages	1	72.6883	72.6883	F = 1.36 P = 0.3296
Station-season interaction	3	160.9351	53.6450	F = 35.60 P < 0.0000001
Residual between weeks of the same season (Error 2)	48	72.3331	1.5069	
Total between weeks	103	40682.0939		
Differences between two depths at separate stations				
Between averages at two depths	1	21.0058	21.0058	F = 7.30 P = 0.0732
Depth-season interaction	3	8.6359	2.8786	F = 15.58 P < 0.0000001
Depth-station interaction	1	38.3904	38.3904	F = 207.74 P < 0.0000001
Depth-station-season interaction	3	1.0955	0.3652	F = 1.98 P = 0.1130
Remainder (Error 3)	96	17.7419	0.1848	
Total	207	40768.9634		

Table 38. (Continued)

ts for between season means = 9.11[1]

ts for between station means = 3.23 (5 percent)[2]

ts for between station means of same depth = 0.46 (1 percent), 0.34 (5 percent)[3]

ts for between station means of same depth in the same season = 0.91 (1 percent), 0.68 (5 percent)[3]

ts for between means at two depths = 0.75 (5 percent)[4]

ts for between means at two depths of the same station = 0.22[5]

ts for between means at the two depths at same station in the same season = 0.44 (1 percent), 0.33 (5 percent)[5]

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[1] s calculated from error 1, based on 3 degrees of freedom.

[2] s calculated from mean square for station-season interaction, based on 3 degrees of freedom.

[3] s calculated from error 2, based on 48 degrees of freedom.

[4] s calculated from mean square for depth-season interaction based on 3 degrees of freedom.

[5] s calculated from error 3, based on 96 degrees of freedom.

Table 39. Differences in seasonal and annual averages of the mean weekly minimum soil temperatures in degrees F. between the two stations, and between the two depths at the same station.

Season	Differences (Open - stand)				Differences (Surface - 6 inches)			
	Soil surface	At 6-inch depth	ts		In the plantation	In the open	ts	
Autumn	- 1.47	0.63	0.91*	0.68**	- 0.11	- 2.21	0.44*	0.33**
Winter	- 1.45	0.32	0.91	0.68	0.86	- 0.91	0.44	0.33
Spring	1.25	2.97	0.91	0.68	0.26	- 1.46	0.44	0.33
Summer	2.96	4.26	0.91	0.68	- 0.11	- 1.41	0.44	0.33
Mean of year	0.32	2.05	0.46*	0.34**	0.23	- 1.50	0.22	

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*1 percent
**5 percent

The seasonal and annual ranges between the maximum and minimum soil temperatures at the two depths at the two stations are given in Table 40. This table shows clearly the much wider range in temperature in the open area than in the plantation. The range of the surface temperature in the open area was almost twice that in the plantation, and at 6 inches was about one and one-half times as much. The range of the temperature at the depth of 6 inches was much less than at the surface, it being only about half of that at the soil surface.

The mean weekly soil temperatures at the soil surface and those at the depth of 6 inches at the two stations are plotted in Figure 8. The highest surface soil temperature for both stations was during the week of July 12 to 18, 1937. The mean temperature of that week was 79.4 degrees F. in the plantation and 86.1 degrees F. in the open area. The lowest was in the week of December 21 to 27, 1936. In the plantation the mean for that week was 37.6 degrees F. and in the open area it was 36.6 degrees F. The highest and lowest mean soil temperatures at the depth of 6 inches were in the same weeks as mentioned above for the surface temperatures. In the plantation the highest value was 77.5 degrees F. and lowest, 36.2 degrees F. In the open area the highest was 85.1 degrees F. and the lowest was 36.0 degrees F.

The mean weekly maximum and minimum temperatures at the soil surface and those at the depth of 6 inches at the two stations are plotted in Figure 9. The highest mean maximum in the plantation was 87.1 degrees at the surface and 82.0 degrees F. at the depth of 6 inches. The highest corresponding values in the open area were 97.6 degrees F. and 91.6 degrees F. All these mean maxima occurred in the week of July 12 to 18, 1937. At the soil surface, the lowest mean maximum in the plantation was 41.7 degrees F.

Table 40. Seasonal and annual ranges of mean weekly maximum and minimum soil temperatures in degrees F. at two depths at the two stations.

Season	Soil Surface			At the depth of 6 inches		
	In the plantation	In the open	Open plantation	In the plantation	In the open	Open plantation
Autumn	7.98	13.70	1.72	4.98	7.06	1.42
Winter	6.37	12.63	1.88	4.70	7.27	1.55
Spring	12.39	21.13	1.71	7.78	11.44	1.47
Summer	9.24	15.33	1.66	5.89	8.73	1.48
Mean of year	9.20	15.69	1.71	5.84	8.62	1.48

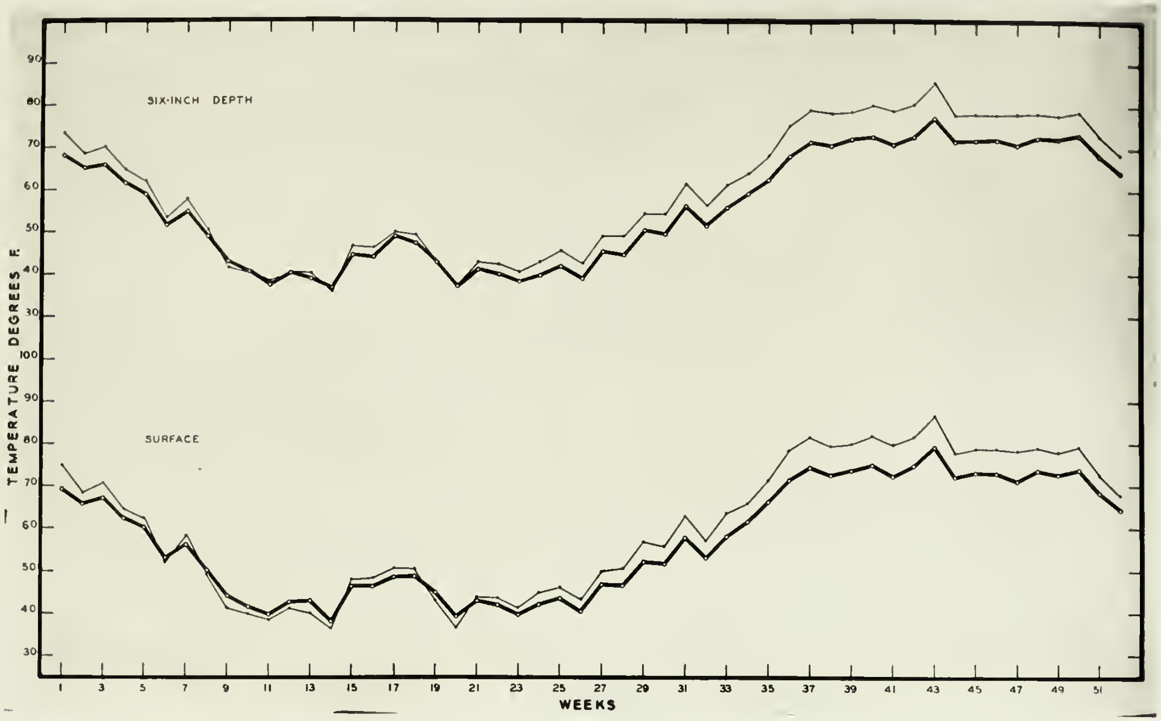

Figure 8. The weekly mean soil temperature at two depths at the two stations from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The heavy lines represent the plantation and the light lines represent the open area.

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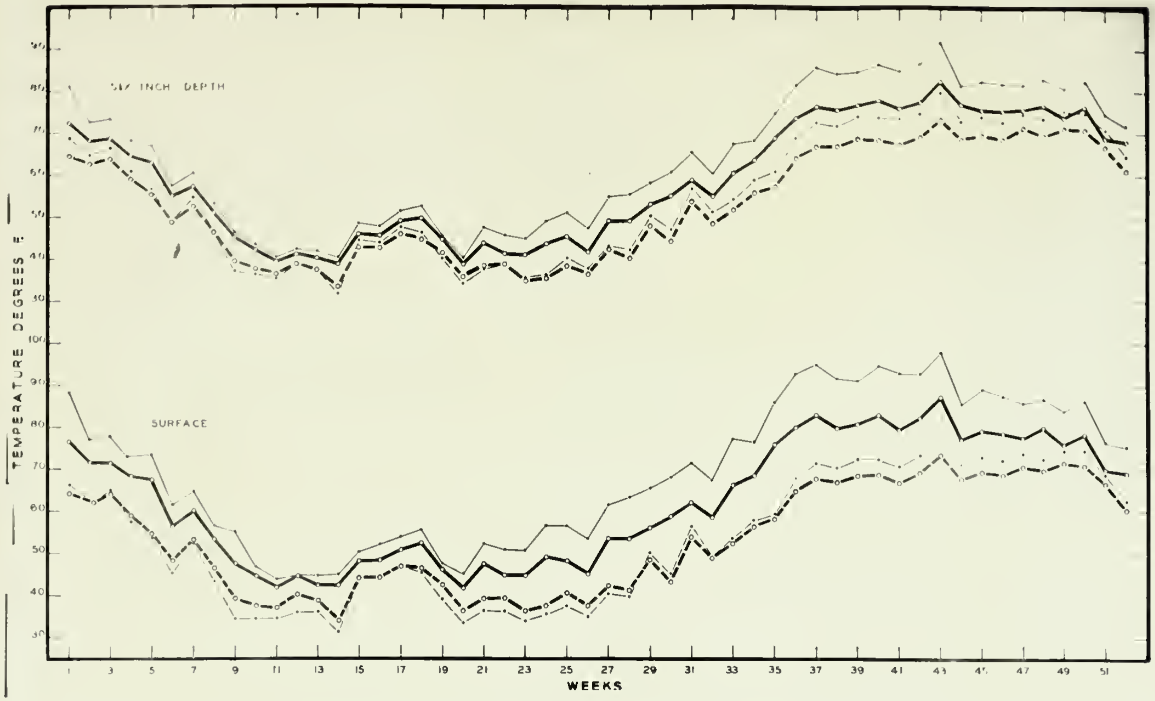

Figure 9. The weekly maximum and minimum soil temperatures at two depths at the two stations, from week 1 (September 21 to 27, 1936) to week 52 (September 13 to 19, 1937). The maximum temperature is indicated by solid lines and the minimum by broken lines. The heavy lines represent the plantation and the light lines represent the open area.

which was in the week of February 1 to 7, 1937, while in the open area the lowest minimum was 43.9 degrees F. which occurred during the week of November 30 to December 12, 1936. At the depth of 6 inches the lowest maximum in the plantation was 39.1 degrees F., and in the open area it was 40.3 degrees F., both of which occurred in the week of February 1 to 7, 1937. (In the open area the same low maximum, 40.3 degrees F. also occurred in the week of December 21 to 27, 1936). The highest maximum temperatures at the soil surface were 73.7 degrees F. in the plantation, and 78.0 degrees F. in the open area, both of which occurred during the same week when the highest maximum temperatures occurred, that is, in the week of July 12 to 18, 1937. The lowest minimum at the surface was 33.7 degrees F. in the plantation, and 31.6 degrees F. in the open area. At the depth of 6 inches the lowest minimum in the plantation was 33.1 degrees F. and 32.1 degrees F. in the open area. All these four minima occurred in the same week of December 21 to 27, 1936, which was also the date of the lowest mean soil temperatures at the two depths.

In the foregoing paragraphs it has been shown that in most cases the soil temperatures, including mean and maximum, between the two stations were significantly different, whether it was at the surface or at the depth of 6 inches. It has been shown that the temperatures at the two depths at each station were also significantly different. By further analysis of variance of the differences of temperatures between the two depths at the two stations, it can also be shown that these differences were also significant between these two stations. For the sake of clearness these differences in temperature between the two depths at the two stations are shown in Table 41, and the results of analysis of variance are given in Table 42.

Table 41. Differences in mean, maximum, and minimum soil temperatures in degrees F. between the two depths at the two stations.

Season	In the plantation (Surface - 6 inches)			In the open area (Surface - 6 inches)		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
Autumn	1.07	2.89	- 0.11	0.08	4.43	- 2.21
Winter	1.55	2.89	0.86	1.04	4.45	- 0.91
Spring	2.23	4.87	0.26	1.96	8.23	- 1.46
Summer	1.05	3.24	- 0.11	0.62	5.19	- 1.41
Mean of year	1.48	3.47	0.23	0.92	5.57	- 1.50

Table 42. Analysis of variance of the differences of soil temperatures at two depths af the two stations.

(1) For mean soil temperature:

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	1	0.6050	0.6050	F = 12.45 P = 0.0374
Between seasons	3	2.6678	0.8895	F = 18.30 P < 0.001
Error	3	0.1457	0.0486	
Total	7	3.4185		

(2) For maximum soil temperature:

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	1	8.8410	8.8410	F = 23.95 P = 0.0160
Between seasons	3	11.3519	3.7840	F = 10.25 P = 0.0446
Error	3	1.1077	0.3692	
Total	7	21.3006		

(3) For minimum soil temperature:

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	1	5.7335	5.7335	F = 46.96 P = 0.0064
Between seasons	3	1.3291	0.4430	F = 3.63 P = 0.0851
Error	3	0.3662	0.1221	
Total	7	7.4248		

Comparison of Air and Soil Temperatures:

Although air temperature is not as important as the many other factors that affect soil temperature, it would not be out of place to compare the two as they were observed in this investigation. Some interesting facts were obtained in such comparisons. In Table 43 are shown the mean seasonal air temperatures at the two stations and also the mean seasonal soil temperatures at two depths at the same station. The interesting fact revealed by this table is that in the open area all the mean soil temperatures, except those at the depth of 6 inches in the winter, were higher than the air temperatures, while in the plantation all mean seasonal soil temperatures were lower, except surface temperature in the autumn. In the plantation the greater differences occurred in the soil at the depth of 6 inches while in the open area the greater differences were at the soil surface.

In Table 44 are shown the mean seasonal maximum air and soil temperatures. From this table it is seen that all the maximum soil temperatures were lower than the air maxima, except in the surface temperatures of the spring and summer seasons in the open area. In Table 45 are shown the mean seasonal minimum air and soil temperatures. All soil minima were higher than the air minima as indicated in the table.

A third comparison was that of the range between the maximum and minimum temperatures. This is given in Table 46. The range in air maxima and minima was much higher than that of soil temperatures. The range in soil temperature in the plantation was only about 25 to 40 percent of that of the air temperature. The range was much greater in the open area. It ran from about 40 to 70 percent of that of the air temperature. The soil

Table 43. Comparison of mean seasonal air and soil temperatures in degrees F. at the two stations.

Season	In the plantation			In the open area		
	Air temp.	Soil temp.	Difference (Air - Soil)	Air temp.	Soil temp.	Difference (Air - Soil)
Autumn	53.08	Surf. 53.17	- 0.09	51.56	Surf. 53.88	- 2.32
		6 inch. 52.10	0.98		6 inch. 53.80	- 2.24
Winter	44.69	Surf. 43.32	1.37	43.54	Surf. 44.22	- 0.68
		6 inch. 41.77	2.92		6 inch. 43.18	0.36
Spring	63.34	Surf. 60.70	2.64	61.72	Surf. 65.31	- 3.59
		6 inch. 58.47	4.87		6 inch. 63.35	- 1.63
Summer	74.92	Surf. 72.89	2.03	72.91	Surf. 78.28	- 5.37
		6 inch. 71.84	3.08		6 inch. 77.66	- 4.75
Mean of year	59.01	Surf. 57.52	1.49	57.43	Surf. 60.42	- 2.99
		6 inch. 56.04	2.97		6 inch. 59.50	- 2.07

Table 44. Comparison of mean seasonal maximum soil and air temperatures in degrees F. at the two stations.

Season	In the plantation			In the open area		
	Air temp.	Soil surface	At 6-inch depth	Air temp.	Soil surface	At 6-inch depth
Autumn	65.04	57.51	54.62	63.17	61.76	57.33
Winter	55.04	46.90	44.01	53.41	51.35	46.90
Spring	78.49	67.42	62.55	75.56	77.41	69.18
Summer	87.97	78.30	75.06	85.17	87.35	82.16
Mean of year	71.64	62.53	59.06	69.33	69.46	63.89

Table 45. Comparison of mean seasonal minimum soil and air temperatures in degrees F. at the two stations.

Season	In the plantation			In the open area		
	Air temp.	Soil surface	At 6-inch depth	Air temp.	Soil surface	At 6-inch depth
Autumn	43.26	49.53	49.64	41.18	48.06	50.27
Winter	35.24	40.17	39.31	33.57	38.72	39.63
Spring	50.24	55.03	54.77	48.62	56.28	57.74
Summer	65.56	69.06	69.17	63.32	72.02	73.43
Mean of year	48.58	53.45	53.22	46.67	53.77	55.27

Table 46. Comparison of the soil and air temperature ranges between maximum and minimum in degrees F. at the two stations.

Season	In the plantation			In the open area		
	Air temp.	Soil Surface	At 6-inch depth	Air temp.	Soil surface	At 6-inch depth
Autumn	21.78	7.98	4.98	21.99	13.70	7.06
Winter	19.84	6.73	4.70	19.84	12.63	7.27
Spring	28.25	12.39	7.78	26.94	21.13	11.44
Summer	22.41	9.24	5.89	21.85	15.33	8.73
Mean of year	23.06	9.20	5.84	22.60	15.69	8.62

temperature range as expressed in percentage of air temperature range is given in Table 47 for the four seasons and for the entire year.

In the foregoing comparisons it can be readily seen that soil temperatures had a close relation to air temperatures, they increased as the air temperatures increased. It seemed that soil temperatures were quite dependent on air temperature. Further to clarify the cause of difference in soil temperature between the two stations, in order to find out whether the variation was due to air temperature or something else such as location of the stations, the method known as analysis of covariance was used (Snedecor, 1934, 1938). For the sake of saving time and labor only seasonal values for the mean temperatures given in Table 43 were analyzed. Before the analysis of covariance was carried out both the air temperature and the soil temperature were subjected first to an analysis of variance. The results as given in Table 48 showed that only the air temperature and the difference of soil temperature at two depths at the two stations were significant, while the sum of the soil temperature at the two depths was not significant. This preliminary procedure determined that there was no need to calculate the covariance for the sum of soil temperatures at the two depths. The results of analysis of covariance as given in Table 49 showed that neither the regression of soil temperature on air temperature between two stations, nor that between seasons, was significant. This fact indicated that the change in soil temperature at the two stations was dependent solely on air temperature; that is, if air temperature were held constant, no significant change in soil temperature would occur between the two stations. As this analysis of covariance showed that location of the station did not affect the change of soil temperature, and air temperature was the only discernible factor, the regression of soil temperature on air

Table 47. Soil temperature ranges expressed as percentages of corresponding air temperature ranges at the two stations.

Season	In the plantation		In the open area	
	Soil surface	At 6-inch depth	Soil surface	At 6-inch depth
Autumn	37	23	62	32
Winter	34	24	64	37
Spring	44	28	78	42
Summer	41	26	70	40
Mean of year	40	25	69	38

Table 48. Analysis of variance of the seasonal air and soil temperatures.

(1) For air temperature:

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	1	4.9612	4.9612	$F = 79.38$ $P = 0.0034$
Between seasons	3	997.3403	332.4468	$F = 5319.15$ $P < 0.0017$
Error	3	0.1875	0.0625	
Total	7	1002.4890		

(2) For the sum of soil temperature at the two depths:

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	1	80.7721	80.7721	$F = 7.42$ $P = 0.0732$
Between seasons	3	4430.8398	1476.9466	$F = 135.66$ $P < 0.0017$
Error	3	32.6621	10.8874	
Total	7	4544.2740		

(3) For the difference of soil temperature at the two depths:

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	1	0.6050	0.6050	$F = 12.45$ $P = 0.0374$
Between seasons	3	2.6678	0.8893	$F = 18.30$ $P = 0.01887$
Error	3	0.1457	0.0486	
Total	7	3.4185		

Table 49. Analysis of covariance for the difference of soil temperature at the two depths between the two stations and between seasons.

(1) For between stations:

Source of variation	Degrees of freedom	Sums of squares and products			Errors of estimate		
		Sx^2	$Sx(y - z)$*	$S(y - z)^2$	Sums of squares	Degrees of freedom	Mean squares
Total	4	5.1487	1.6963	0.6536	0.0947	3	
Stations	1	4.9612	1.7325	0.6050			
Error	3	0.1875	- 0.0362	0.0486	0.0416	2	0.0208
Difference for testing adjusted means					0.0531	1	0.0531
					F = 2.5529 P = 0.8485		

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*x = air temperature
y = surface soil temperature
z = soil temperature at 6 inches

Table 49. (Continued)

(2) For between seasons:

Source of variation	Degrees of freedom	Sums of squares and products			Errors of estimate		
		Sx^2	$Sx(y - z)$*	$S(y - z)^2$	Sums of squares	Degrees of freedom	Mean squares
Total	6	997.5278	0.9164	0.9379	0.9371	5	
Seasons	3	997.3403	0.9526	0.8893			
Error	3	0.1875	- 0.0362	0.0486	0.0416	2	0.0208
Difference for testing adjusted means					0.8955	3	0.2985

$F = 14.3510$
$P = 0.8969$

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*x = air temperature
y = surface soil temperature
z = soil temperature at 6 inches

temperature was calculated. Because there were two series of observations on soil temperature, it is very desirable to know first whether the regressions on air temperature were the same or different. This can be easily determined by calculating two regressions, one for the sum of the two series of soil temperatures, and one for their difference. The results as given in Table 50 showed that only the regression of the difference was significant. This meant that they had a different regression. The regression equation for soil temperature at the two depths thus determined are as follows:

$$Y = -1.3767 + 1.0371 X$$

$$Z = -2.4253 + 1.0340 X$$

in which Y and Z are the estimated seasonal soil temperature of the surface and at the depth of 6 inches, respectively, and X is the seasonal air temperature.

Discussion

From the results presented in the foregoing sections it has been shown that almost every microclimatic factor observed at the station in the plantation was different from the same factor observed in the open area. Theoretically, from a statistical point of view, this experiment can be criticized on two points. First, there was not enough duplication of observations--the results analyzed were only for one year, and second, no criteria were available to estimate the error due to the location of the station. If records had been available for more than one year, by analysis of such data it would be possible to show whether the variation between the two stations is real as compared with the change within each station from year to year. If this were the case, the conclusion would be much more convincing than that based only on one year's record, the differences shown could then be

Table 50. Analysis of variance for the regression of mean seasonal soil temperatures at the two depths on mean seasonal air temperatures.

(1) For the regression of the sum of the soil temperatures:

Source of variation	Degrees of freedom	Sums of squares	Mean squares	Observed F
Regression	1	4297.7243	4297.7243	F = 104.59 P = 0.0000398
Error	6	246.5497	41.0916	
Total	7	4544.2740		

b = 2075.6737/1002.4880 = 2.0705   a = 116.7425 - (2.0705)(58.22) = -3.8020

(2) For the regression of the difference of the soil temperatures:

Source of variation	Degrees of freedom	Sums of squares	Mean squares	Observed F
Regression	1	0.0060	0.0060	F = 34.80 P = 1.0000
Error	6	3.4125	0.5688	
Total	7	3.4185		

b = 2.6489/1002.4890 = 0.0026   a = 1.20 - (0.0026)(58.22) = 1.0486

$(Y + Z) = -3.8020 + 2.0705X$ $(Y - Z) = 1.0486 + 0.0026X$

$Y = -1.3767 + 1.0371X$ $Z = -2.4253 + 1.0340X$

Y = estimated surface soil temperature

Z = estimated soil temperature at 6 inches

X = air temperature

proven statistically as not being due to chance of sampling. The criticism from the second point is that although it was possible to prove that the difference between the two stations was significant, there is no evidence to prove that the difference was mainly due to the presence or absence of trees, but not due to other minute topographical differences between these two places. If there were duplication of the stations in these two areas, it would not be a difficult task to show whether the differences of such microclimatic factors were due entirely to location of stations or were merely due to the effect of the planted trees. This could easily be done by comparing the variation between the stations in the same area with that between the two areas. Of course, it would have been much better theoretically, if two sets of recording instruments could have been used for each station, because the accuracy of the recording instruments could then also be estimated. Although the above criticisms are theoretically sound, it would have been almost impossible to carry out in practice because of the time, money, and labor involved. From a practical point of view the design adopted in this investigation had to be considered as satisfactory.

Air Temperature:

Published comparisons of air temperature in forests and in the open were obtained mostly from observations in mature stands, very few observations having been in such young stands as the plantation used in this investigation. The results of this investigation at a glance seem very contradictory to those published previously by many other investigators. If one is reminded of the fact, as pointed out by Fernow and Harrington (Fernow, Harrington, Abbe, and Curtiss, 1893), that a young forest stand has a warming effect while a mature stand has a cooling effect, it is not

difficult to see why the results appearing here are not unexpected. They might be expected because of two generally accepted facts: (1) More solar radiation is absorbed by the vegetation cover than by the bare soil surface. The atmosphere under a cover of vegetation is thus heated much more than that above a bare soil surface. Angstrom (1925, cited by Geiger, 1930, p. D37) has shown that humid surfaces always reflect less, and consequently absorb more, of the solar rays than do dry surfaces. If a vegetation cover is compared with a bare soil surface, the former is much more moist because of transpiration. Therefore, a vegetative cover is always more effective in absorbing solar radiation than a bare soil surface. (2) The atmosphere under the plant cover is in a stagnant condition. Since wind movement is very slight in a stand, there is very little chance of cool air mixing with that in the plantation which has already become heated. This explanation is justified and substantiated by the observations on humidity and wind movement in the plantation.

Although the mean air temperature was raised in the plantation, there was very little change in the range between the maximum and minimum temperature. This would not be very difficult to explain, if the record of the maximum and minimum temperatures were examined. In the plantation not only the maximum was raised, but also the minimum. This is due to the peculiar exchange condition of heat under a vegetation cover. A bare soil surface can be heated up very rapidly, and also cools down very rapidly, so the temperature is more likely to reach the extremes under such condition. The vegetation cover, however, can retain heat longer once it is heated up. This is why the minimum temperature was also higher within the plantation than in the open area outside.

Atmospheric Humidity:

The results obtained from observations on relative humidity in this investigation agreed completely with those published by previous investigators. It is further pointed out in this investigation that the real difference in humidity occurred in the daytime while that during the night was not of very much importance. However, there was one important peculiarity about the atmospheric moisture in the young stand. Although the relative humidity was higher in the plantation than in the open area, it did not necessarily create a condition more favorable to the reduction of transpiration rate, because this more moist condition was offset by the effect of increase in air temperature. An increase in air temperature increased the vapor pressure deficit in which, except in the summer, there was very little difference from that of the open area. This peculiar condition may be attributed to the dryness of the air which was not very much less than that in the open area, although there was more air moisture inside the plantation.

Another interesting fact revealed by this study was the greater difference of the relative humidity between the plantation and the open area in the spring and summer. This may be explained by the higher transpiration rate of the trees during these warm seasons. However, a greater difference in minimum relative humidity occurred in the autumn and winter. This may be explained by the retardation of the drying wind passing through the plantation during these seasons. Much moisture was thus preserved which made the minimum relative humidity higher than in the open area.

Precipitation:

The measurement of rainfall in forest stands is a very difficult task, because it all depends on the place where the rain gauge stands. It has been shown by Hoppe (1896) that with the installation of a single rain

gauge under the crown of a tree, an average error of 25 to 30 percent occurred. In individual cases, however, this error may exceed 100 percent. It is very evident that the results obtained in this investigation are by no means very dependable. The slightly higher, although not significant, quantity of rain collected in the plantation in the autumn, winter, and spring seasons, and the much less rainfall collected in the summer is difficult to explain. According to many previous observers the amount of rainfall intercepted by the crowns was inversely proportional to the volume of rainfall (Hoppe, 1896; and Burger, 1930). The observations here were just opposite, because the rainfall recorded in the autumn and spring was small in volume as compared with that recorded in the summer of that year. Most of the rains during the autumn and spring were less than 1 inch, only a few were a little over 1 inch, and many of them were of a misty nature. The rains were frequent rather than heavy. In the summer season of that year, however, the rainfall was very heavy; during six weeks (August 2 to September 12, 1937) there was 18.62 inches of rain. During that period about one third, 6.01 inches, fell in four days (August 23 to 26) as heavy rain storms. In the same period, however, the rain gauge in the plantation only recorded 4.86 inches of rain, a difference of 19 percent. On the contrary, when the rain fell in smaller volume, the rain gauge in the plantation gave a higher record than that installed in the open area. A few examples will be given here. For October 8 and 9, 1936, the rainfall recorded in the open area was 1.51 inches, but it was 2.16 inches in the plantation. During the period from December 30 to January 3, the rainfall recorded in the open was 3.81 inches, while that in the plantation was 4.06 inches. The causes of such variation in rainfall records between these two stations are difficult to determine, and further studies especially aimed at this kind of problem are needed. The

direction and intensity of wind might have some effect. Although many other investigators have proved that the so-called horizontal precipitation may be of much importance in increasing the precipitation in a forest stand, (Geiger, 1927, p. 168) it is very doubtful if that is true in the present case. If it is considered as one of interception within the crown (interception gain) it is in perfect agreement with results obtained by many other investigators. Working in South Africa, Phillips (1926) reported that a rain gauge screened by branches and leaves of plants registered much higher precipitation than a gauge in the open not screened, especially if the volume of rain is small or of a misty nature (Nebelreissen). If the rain occurred in a heavy downpour, the screened gauge registered less precipitation than an unscreened gauge. It was very similar to the present case.

Air Movement:

The result obtained from the observations on air movement is rather striking in that they showed very clearly the effect of the plantation in checking air movement. The importance of the reduction of air movement by a forest stand does not lie in the retardation effect itself, but in modifying the other microclimatic factors following the checking of air movement. Almost any modification of the microclimatic factors in the plantation observed in the present investigation can be attributed to this effect. The increase in air temperature and relative humidity, decrease in evaporation, are all the consequences derived wholly or partly from the calm condition of the atmosphere in the plantation (Bates, 1911).

Since no daily observation or hourly record was kept, it is impossible to see how the air movement was checked by the young plantation and to what extent. Problems, such as in which part of the plantation is the retardation most effective, and what is the upper limit of wind velocity

to which the young plantation will serve as the best windbreak, are very interesting and need further study. The effect of mature forest stands in reducing wind velocity has become fairly well known through the work of Geiger (1927). He stated that the wind velocity above the forest soil in the interior of the stand always represented a certain percentage of the velocity above a forest, no matter how great it is. In a high pine forest about 65 years of age where he made his observations, it amounted to about 40 percent. If this figure is compared with the results presented here, a young stand is much more effective in checking the air movement than a mature one, because the air movement in the young stand as observed here was only a very small fraction of that in the open area, from 2 percent in autumn to about 10 percent in the spring. (Table 20). How did this happen? By comparing the vertical distribution of the wind velocity in the mature pine stand mentioned above, Geiger reached the conclusion that the total slowing up occurred in the upper portion of the crown canopy, and only in the layer 1 to 2 meters above the forest soil did the wind force decrease again until it reaches zero at the soil surface. Since in a very young stand there is no stem space between the crown canopy and the soil surface, once the wind velocity is slowed down, it will drop very quickly to zero.

Evaporation:

The results obtained from observations on evaporation suggest many interesting points for discussion. The first conclusion that can definitely be drawn from such data is that there was a decidedly different rate of evaporation between the two stations, no matter whether the evaporation was near the ground surface or at a height of 6 feet in the free atmosphere. The evaporation rate in the open area was much higher than that in the

plantation. Near the ground surface the evaporation rate in the plantation was about 60 percent of that in the open area in the autumn, and was only 27 percent in the summer, with intermediate values of 32 to 33 percent for the winter and apring seasons. The difference at 6 feet was even greater. In the autumn the evaporation rate in the plantation was only 32.5 percent of that in the open, about 19 to 20 percent in the winter and summer, and 24 percent in the spring. (Table 22).

The decrease in evaporation in the stand may be attributed to the following reason: According to a law of physics, evaporation is proportional to the solar radiation and air movement. Although no collateral observations on solar radiation were made accompanying those on evaporation, some information may be had by comparing black and white bulb atmometers during July to October, 1936. Such records show that the average intensity of solar radiation in the plantation at the height of 6 feet was only about 34 percent of that in the open area, and it was still less at the soil surface, only about 15 percent. The average intensity for the four months from July to October, inclusive, at the height of 6 feet were 57.0, 39.2, 26.7, and 12.6 percent, and those at the soil surface were 17.3, 15.3, 14.4, and 12.5 percent, respectively. The effect of sunshine on evaporation has also been observed by many other investigators. Okada (1931), making observations near Tokyo, Japan, showed that the annual evaporation in the shade, averaged for 18 years, was only 44 percent of that in the sunshine (Cited by Conrad, 1936, p. B 363). The effect of the air movement is too evident to be discussed here as it has been emphasized elsewhere. It has also been shown in the calculation of regression that wind was the only significant common factor in causing a change in evaporation in the open area.

The same explanation can also be used to account for the small difference in evaporation between the two positions in the plantation in the autumn. In the autumn the atmosphere was especially calm as compared with the other seasons, as shown by the wind movement record, and the solar radiation between the two positions was almost equal as compared with solar radiation in the same position in the open area. The increase of solar radiation at the soil surface can also be proved in another way. If the solar radiation of the soil surface during the four months is expressed in percentage of that at the height of 6 feet, the percentages are 29.3, 35.3, 49.5, and 63.3 for July, August, September, and October, respectively. It can be seen that the solar radiation in October was double that in July. This increase may also mean that the radiation intensity at the 6-foot height was decreased due to the angle of the sun's rays. The stagnant condition of the air and the decrease in solar radiation were responsible for the reduction of evaporation at the higher position, bringing the rate of evaporation close to that near the soil surface. In the winter, as the wind movement became stronger, a condition which would affect evaporation at the higher position more than at the soil surface, the evaporation rate at 6 feet again increased.

In the open area, however, the situation is different. Although there was a seasonal difference in wind movement, it was strong throughout the year. If the solar radiation is compared, not much difference will be shown. The monthly averages of solar radiation intensity at the soil surface as expressed in percentage of that at a height of 6 feet for July to October were 89.7, 91.1, 92.3, and 64.5 percent, respectively. Although the differences in solar radiation between the two positions was almost the same in the summer, there was still a difference in evaporation

of more than 50 percent. (The annual evaporation at the soil surface was only about 47 percent of that at 6 feet.) (Table 22). The main reason for this was the difference in wind velocity between the two positions.

Although wind velocity was measured only at the height of 6 feet in this study, the decrease of wind effect near the ground has been shown by many other investigators. Hellmann (1919, cited by Geiger, 1927, p. 71) recorded the wind movement at five different heights above the ground, namely, at 5, 25, 50, 100, and 200 cm. He found that the relation of the wind velocity at the different heights could be expressed by the following equation:

$$V = v\,H^{\underline{a}} \text{ or } (\log V - \log v) = \underline{a} \log H$$

in which V = the wind velocity at the height H, v = wind velocity observed at 1 meter, and $\underline{a}$ = a constant derived from data of the experiment. This equation simply shows that the wind velocity increases with increase in height, or, expressed another way, wind movement is least near the ground surface. His conclusion was later modified by Peppler (1921) who found that wind velocity between two heights (o and 2 meters) was not different unless the wind attained a velocity of more than 1.3 meters per second. In other words, his statement showed that the higher the wind velocity the more different it would be between the two levels.

Soil Temperature :

The lowering of soil temperature under the cover of a forest stand can be explained by insulation. The heating of the soil is due chiefly to the absorption of solar radiation by the soil. Once a bare soil surface is covered with vegetation, much less direct radiation will reach the soil surface, and it is absorbed by the vegetation instead. Angstrom (1925,

cited by Geiger, 1927, p. 154) measured in an open area with aid of a pyrheliometer, a solar radiation of 0.99 gram calories per square centimeter per minute, on June 28, 1925. At the same time the amount received in the interior of a pine forest 15 meters high was 0.04; it was 0.02 to 0.03 in a mixed forest of spruce, oak, and poplar 10 to 20 meters high; while in pure spruce forest 20 meters high, it was only 0.01 or less. The soil surface is insulated from the radiation of the sun. On account of this, the soil temperature under a forest cover will not go as high as that of the bare soil. Such insulation effect of plant cover on the soil can be attested by the fact that during the summer months the daily maximum in the open area occurred about 2 o'clock in the afternoon, while in the plantation it did not occur until about 4 o'clock.

Although the protection of the forest stand against the severe cold soil temperature in the winter season cannot be proved by the observations on the mean soil temperature in this investigation, it still can be said that such evidence was not entirely lacking. If the seasonal changes in minimum temperature are examined, it can be seen that during the autumn and winter the minimum surface soil temperature in the plantation was higher than that in the open area (Table 29). This is very good evidence that the soil temperature in winter and autumn was much more moderate in the plantation than in the open area.

The forest stand not only changed the temperature of the soil, but it also changed the conductivity of the soil, so to speak. This is evidenced by the discordance of differences in temperature between the two depths at the two stations. As pointed out in a foregoing paragraph, the difference in mean temperature between the two depths was always greater in the plantation than in the open area. This fact leads to the inference

that the cooling effect of the forest had a greater influence on the soil at a depth of 6 inches than at the soil surface. The explanation for this may be attributed to the effect of the forest stand on the minimum temperature at that depth. If the minima at the two depths in the open area are compared, it will be found that all the minima were higher than those at the surface. This is because the soil at 6 inches is subjected to less intense radiation than is the surface soil after the atmosphere has cooled down at night. In the plantation, however, the minimum at a depth of 6 inches was either lower than that at the surface or only slightly higher. (Table 39). This is because solar radiation was very much less intense in the plantation, and the heat could never reach a depth equal to that in the open area. After the sun set the soil below the surface cooled quickly and to a greater degree than the surface soil. This will explain why the temperature of the deeper soil in the plantation was always lower than the surface soil.

STUDIES OF SOIL FACTORS

The comparative study of soil conditions was carried out in two plantations, Plantation 4 in Compartment 51, and Plantation 6 in Compartment 67. The soil type of Plantation 6 was identified first as Georgeville silt loam according to the nomenclature given by Perkin and others (1924). But after samples of the surface soil were analyzed in the laboratory, it was found that there was a much higher percentage of clay and a much lower content of silt than the name indicated. According to the scheme given by Davis and Bennet (1927), it should be called clay. It was decided to call it Georgeville stony clay. (See Table 51.) The soil type of Plantation 4 where studies of microclimatic factors were carried out simultaneously, was identified as Whitestore sandy loam. Later, however, it was discovered that the soil of the northeastern half of the plantation and that of the open field on its northern border were slightly different from that of the southwestern half of the plantation. The former was described as a new series by the Bureau of Chemistry and Soils of the U. S. Department of Agriculture, although, as yet it has not appeared in any publication. It was named Creedmoor series. Therefore, to conform with the nomenclature of the Bureau of Chemistry and Soils, the name of the soil in the northeastern

Table 51. Results of mechanical analysis of the surface soils (A horizon) at the five stations.

Station	Horizon	Percentages of Particles by Diameter-Size Classes in Millimeters						
		Total sand 2.0 to 0.05	"Total Colloid"	Silt 0.05 to 0.005	Clay 0.005	Fine Clay 0.002	Gravel 2.0	Textural Grade
1	A_1	82.83	9.89	10.39	6.77	6.02	2.64	sand
	A_2	66.75	23.22	15.41	17.83	15.34	1.10	sandy loam
	Average	74.79	16.56	12.90	12.30	10.68	1.87	sandy loam
2	A_1	83.08	9.86	10.08	6.84	5.08	3.27	sand
	A_2	76.08	16.98	11.22	12.70	10.82	4.70	sandy loam
	Average	79.59	13.42	10.65	9.77	7.95	3.98	sandy loam
3	A	40.89	35.91	29.76	29.34	26.18	2.60	clay loam
4	A	41.55	42.38	25.60	32.83	27.98	22.25	stony clay
	AB	36.33	48.89	25.50	38.16	33.10	10.94	stony clay
5	A	37.93	48.89	20.69	41.38	35.84	16.20	stony clay

half and in the open field was changed to Creedmoor sandy loam.

Erosion had been evident before trees were planted in the areas now comprising the two plantations. In Plantation 4, erosion was limited more or less to the southwestern half on the Whitestore soil; in Plantation 6, the eroded places were scattered in irregular patches of various sizes, known as "gall" spots. Observations and comparisons were made at five stations which represented different kinds of soil conditions: namely, (1) on Creedmoor sandy loam in open field; (2) on Creedmoor sandy loam in the plantation; (3) on eroded Whitestore sandy loam in the plantation; (4) on uneroded Georgeville stony clay; and (5) on eroded Georgeville stony clay. Both (4) and (5) were in the plantation. Hereafter, these five stations will be referred to by their numbers in the order as given above.

Methods of Study

To examine soil profiles, soil pits were dug at each station. They were rectangular in shape, approximately 6 by 1.5 by 3 feet in size. In all, 20 soil pits were dug with four at each station. The soil pits were dug about from 30 to 50 feet apart, and were always located so that they can be considered as representative of that place. When they were dug in the plantations, they were placed at a distance of 2 or 3 feet from a tree. At the time the soil pit was dug, the surface nearest to the tree was smoothed off, and a string grid with intervals of 6 inches was laid on it. After this, the soil horizons and distribution of roots were mapped on cross-section paper. The profiles were mapped 5 feet horizontally and three feet vertically. After this was done, soil samples of about two quarts, composited through the whole extent of each horizon, were collected to be used for analytical work. In the laboratory such samples were air dried,

rolled, and then sieved through a 2 mm. sieve to remove gravel. The amount of gravel was expressed in percentage of the total weight of the soil sample.

To test the homogeneity of the upper layer of the surface soil, samples were collected by another method. In each place a square area of about 30 by 30 feet was laid out close to the place where the soil pits were dug, then this was divided into a 5 by 5 Latin square; from each compartment of the Latin square, five ssmples of the surface soil layer from 4 to 5 inch depths were taken by driving into the soil a steel cylinder of about one pint capacity (Coile, 1936b). These samples were thoroughly mixed in a wooden box, and about one pint of the composite sample from each compartment of the Latin square was collected for use in the laboratory. Twenty-five such composite samples were collected from each place. Moisture equivalents, wilting percentage, and organic carbon content were determined for these samples.

The hydrometer method of Bouyoucos (1927a, 1927b, 1928a, 1928b, 1930) was used in making mechanical analyses of the soil samples. Based on the results of mechanical analysis, the textural grade of each horizon was then classified according to the scheme given by Davis and Bennett (1927). Moisture equivalents of the soils were determined according to the procedure given by Veihmeyer, Oserkowsky, and Tester (1928). Wilting percentages of the upper horizons (including A and B) for each station were determined by the method described below. Cardboard cartons of pint size were used for growing the plants. These cartons were first made water proof by coating them with paraffin. They were filled between one-half and two-thirds full of air-dry soil and water was then added slowly to bring the moisture content of the soil up to near the moisture equivalent. Oat seeds which had been

soaked for 24 hours were then planted in amounts sufficient to cover the soil surface. On top of the seeds was put a thin layer of soil, which was then moistened. A small amount of water was added daily to keep the moisture content of the soil about the level of the moisture equivalent, until the oat plants were about one inch high. When they were about two inches high, the surface of the soil was sealed with paraffin to a depth of about 1/8 an inch and the plants were allowed to grow until permanent wilting was apparent. It was considered that the permanent wilting point was reached when the plants did not recover after being placed overnight in a saturated atmosphere, such as that in a greenhouse. The plants with the soil mass were then removed from the container, the soil was shaken from the mass of roots and mixed thoroughly, and from this was taken a sample of about 75 grams. The moisture content of the soil was determined by weighing immediately, and reweighing after it was dried in an oven for 24 hours at 105 degrees C. The moisture content was expressed in percentage of the oven-dried soil. All the determinations for mechanical analysis, moisture equivalent, and wilting percentage were made in duplicate, but only the average values are presented.

Volume weight, water-holding capacity, and air capacity of the soils were determined from samples collected with a soil sampling device designed by Coile (1936b). The samples were obtained by placing the steel cutting cylinder (with a brass cylinder in it) on a level surface, and pounding it into the soil vertically. After the cylinder was driven down to the level of the soil surface, it was dug up with a mattock or pick and spade, taking special care that the sample inside the cylinder would not be disturbed. The inner cylinder with the soil in place was then removed, the excess soil trimmed away, and the lids put on to keep the soil from

falling out. Three samples were collected from each horizon. When the cylinders were brought back to the laboratory, the top lids were removed and replaced by paper and wire screens. The brass cylinder was submerged in water with the screened end downward to prevent soil running out, and the other metal lid removed. When the soil had been allowed to soak for at least 24 hours, the lid was replaced, the whole combination turned over under water, and then taken out. The excess water was wiped off and the sample was weighed immediately. The cylinder was then turned over with the screened end down, allowed to drain on a sand bed for two hours, and then reweighed. The difference between the first and second weighing which is expressed in percentage of the total volume of the sample, is a measurement of the air capacity. After the second weighing, the sample was oven-dried at 105 degrees C. and the weight of the oven-dried soil was determined. The water-holding capacity of the soil is the amount of water held in the soil at the time of the second weighing. Allowing one gram of water equal to one cubic centimeter of water, the water-holding capacity is also expressed in percentage of the total volume of the sample (600 c. c. = the volume of the brass cylinder). The weight per unit volume of the oven-dried soil is its volume weight.

Only two chemical properties of the soils were studied; namely, carbon and organic matter content, and soil acidity (pH). The carbon and organic matter content of the soil was determined by a modification of Schollenberger's (1931) method, using chromic acid as oxidizing agent, and ferrous ammonia sulfate to titrate against the excess of acid not reduced by the soil, from which the amount of carbon and organic matter can be calculated. The pH of the soil was determined electrometrically with a Beckmann pH-meter*, using glass electrode and a 10 percent suspensoid

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*Manufactured by National Technical Laboratories, Pasadena, California.

solution of the soil. Only the soils from the A horizons were analyzed for their carbon and organic matter content, but pH was determined for all the horizons.

The total soil moisture (holard) of the upper 18 inches (A and B horizons) was determined periodically at the five stations. Determinations were made at about 2-week intervals from May to September, 1937. Soil samples of from 100 to 200 grams were taken from a known depth with the aid of a soil auger, and put directly into a seamless metal soil can. Six samples were collected from the upper 3 or 6 inches (A or A_1 horizons). Fresh weight of such samples was determined immediately after they were brought to the laboratory, and then they were oven-dried at 105 degrees C. until the weight was constant. The loss of weight of the soil expressed in percentage of that of the oven-dried soil is the total moisture content. The difference between the total moisture content and the wilting percentage as determined from samples collected from the soil pits, is the available soil moisture (chresard) of that soil.

Results of the Study

Soil Profile:

Because all the soils examined had been cultivated for quite a long time, the profiles were very much disturbed, especially the upper horizons, and had lost many of their original characteristics. The definitions of horizons used in the description of a virgin soil cannot be applied here without some modification. The profiles of the soils examined can be divided into two parts, the surface soil (A horizons), and the subsoil (B horizons), which roughly equal the A and B horizons of a virgin soil. The upper 6 inches of the A horizon of the soil at stations 1 and 2

has a much darker color than the soil of the same horizon just beneath it. This dark colored zone which is generally known as "ploughed layer", has a higher organic content as a result of cultivation by which more organic matter was incorporated into the soil. This "ploughed layer" will be called the A_1 horizon tentatively in the description presented here, with an analogy to the term used for a true virgin profile, while that part just beneath it will be called A_2 horizon. For the other three stations, however, there was no such distinction evident; they are simply called A horizons.

Since the profile of the soil at stations 1 and 2 is identical, one description will suffice. The soil of the upper 12 to 18 inches, generally light gray in color, is designated as the A horizon and is composed of sandy loam. From 0 to 6 inches is the A_1 horizon, which differs from the A_2 horizon just beneath it by its darker color and higher percentage of sand. From 6 to 12 inches, sometimes to 18 inches, is the A_2 horizon which sometimes has a distinct yellowish tinge instead of light gray. From 12 inches down to 30 or 36 inches is the B horizon which is composed of sandy clay or clay. The upper 12 inches of the B horizon, which is yellowish red, is distinguished as B_1. The zone below it is distinguished as B_2 which is more reddish in color, sometimes of brick red, and more sticky. The boundary between A_1 and A_2 is sharply defined, but that between A_2 and B_1, and that between B_1 and B_2 merge gradually and are not very distinct. No distinction of the profiles between the soils at stations 1 and 2 is present, except that at station 2, an A_0 horizon has begun to accumulate, although it is still in an initial stage, and can hardly be taken as a distinguishing characteristic of the soil profiles of these two places.

Much of the A horizon of the soil at station 3 has been washed

away. In most places only about 2 to 3 inches are left, although in some less severely eroded places, there may be about 6 inches. The A horizon is a clay loam brownish gray in color. The B horizon is a stiff, sticky, plastic clay, dull red in color, about 20 to 30 inches thick. On exposure to the air, it breaks down into cubical fragments. Drainage in the B horizon is very poor, in the wet season it was found always saturated with water; in the dry season, it became as hard as cement when it was dried out.

The profile of the soil at stations 4 and 5 is very much alike and will be considered as one. The A horizon is a grayish yellow stony clay, usually about 6 inches thick, but due to erosion, it is only about 2 to 3 inches thick in some places. In a few places the A horizon passed into another compact layer at a depth of about 6 inches. This compact layer, yellowish red in color, is named the AB horizon. The B horizon is a more or less brittle clay, bright red in color, which may go down as deep as 3 feet without any recognizable change. The soil of the B horizon is much more pervious than that of the soil at station 3.

Physical Properties:

The physical properties of the soils were studied by means of mechanical analysis and by determinination of moisture equivalent, wilting percentage, volume weight, water-holding capacity, and air capacity. The results of mechanical analysis for each horizon of the soils at the five stations are shown in Tables 51 and 52. The results of the other properties are shown in Table 53. All the figures used in these tables are averages for the four soil wells dug at each station.

From Table 51 it can be seen that the texture of the surface

Table 52. Results of mechanical analysis of the subsoils (B horizons) at the five stations.

Station	Horizon	Percentages of Particles by Diameter-Size Classes in Millimeters						
		Total sand 2.0 to 0.05	"Total Colloid"	Silt 0.05 to 0.005	Clay 0.005	Fine Clay 0.002	Gravel 2.0	Textural Grade
1	B_1	44.24	48.66	11.76	44.00	41.24	2.05	clay
	B_2	43.61	46.34	15.71	40.67	37.06	1.22	clay
2	B_1	53.29	40.73	9.30	37.40	35.66	3.20	sandy clay
	B_2	49.66	41.29	13.37	36.96	34.85	2.65	sandy clay
3	B_1	25.00	59.36	22.86	52.15	48.92	1.02	clay
	B_2	28.42	45.58	35.34	36.24	31.86	0.39	clay
4	B_1	17.11	72.92	19.18	63.70	57.86	2.05	clay
	B_2	16.46	70.41	24.36	59.17	51.81	0.43	clay
5	B_1	11.52	83.51	12.74	75.72	71.98	0.54	clay
	B_2	13.27	77.16	17.83	68.88	63.01	0.32	clay

Table 53. Physical properties of the surface soils (A horizons) and subsoils (B horizons) at the five stations.

Station	Horizons	Volume weight	Air capacity	Water-holding capacity In percent of weight	Water-holding capacity In percent of volume	Moisture equivalent	Water-holding capacity / Moisture equivalent	Wilting percentage	Moisture equivalent / Wilting percentage
1	A_1	1.48	5.62	21.22	31.22	5.91	3.60	0.78*	7.09*
	A_2	1.71	4.48	15.57	26.46	10.40	1.50	2.40	4.30
	B_1	1.58	4.46	23.26	36.37	27.31	0.86	13.65	2.01
2	A_1	1.42	9.28	21.04	29.85	5.16	4.10	0.84*	5.50*
	A_2	1.55	7.33	17.32	26.83	8.04	2.24	1.19	6.99
	B_1	1.60	5.70	20.63	32.79	22.13	0.96	10.89	2.16
3	A	1.33	6.05	30.72	40.32	17.47	2.06	7.26	2.57
	B_1	1.32	3.78	35.39	46.14	30.89	1.15	14.73	1.91
4	A	1.39	8.65	25.70	36.35	20.36	1.26	6.33*	3.01*
	B_1	1.33	6.70	31.45	40.60	33.31	0.95	19.52	1.73
5	A	1.32	8.15	30.98	40.73	22.34	1.40	9.24	2.42
	B_1	1.28	6.18	36.76	46.66	36.50	1.01	23.26	1.58

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*Average values from the determinations made on composite samples collected from Latin squares.

soils at stations 1 and 2 is the same. Both are characterized by a high percentage of sand and a very low percentage of "total colloid." The higher percentage of sand in the A_1 horizon, and the increase of the "total colloidal" content in the A_2 horizon are good illustrations to show that eluvial action has been going on in the A horizon of this soil. The surface soil at station 3 is distinguished from all the others by its medium texture which is heavier than that at stations 1 and 2, but lighter than that at stations 4 and 5. The heavy soil texture of the surface soil at stations 4 and 5, with its high percentage of "total colloid" and clay and its stony character, will readily distinguish it from all the others.

From Table 52 a similar relation can be shown in the subsoils. The subsoil at stations 1 and 2 is characterized by its high percentage of sand, being either a clay or a sandy clay. Although the subsoils of stations 3, 4, and 5 are classified as clay, they are different from each other. The clay of the subsoil at station 3 contains more sand but less clay than the subsoils at stations 4 and 5. The highest percentage of clay is found in the subsoil at stations 4 and 5.

The difference in volume weight of soils at the five stations is shown in the first column of Table 53. The volume weight of the soil at stations 1 and 2 is higher than those at the other three stations. The higher percentage of sand both in the surface soil and subsoil at stations 1 and 2 may be considered as an explanation of the greater volume weight shown by these soils.

As a general rule, air capacity of the soils studied, decreases on going down from the surface soil to the subsoil. Contrary to air capacity, the water-holding capacity increases, either in percentage of weight or in percentage of volume, from the surface soil to the subsoil. The

moisture equivalent and wilting percentage increase when the texture of the soils becomes heavier, but the ratio of moisture equivalent to wilting percentage decreases when the texture of the soil becomes heavier.

Chemical Properties:

The results of studies on chemical properties of the soils are presented in Table 54. From this table it can be seen that the surface soil, except at station 3, is less acid than the subsoil. The organic matter is richer in soils which were not eroded (stations 2 and 4) than in the eroded soils (stations 3 and 5), and it is also higher in the plantation (station 2) than in the open field (station 1).

Special Studies of the Upper Surface Soils:

It has been mentioned in a previous section that composite samples of soil from 4 to 5 inches at the soil surface were collected by laying out Latin squares. The physical and chemical properties of such samples were also determined. Mechanical analyses of such samples were made by combining the 25 composite samples from each place into a single sample. The results of the mechanical analyses are shown in Table 55. If figures in this table are compared with those given in Table 53, it can be seen that they are very close to each other. This fact shows that the mechanical composition of the surface soil in each place is very homogeneous.

Moisture equivalent and wilting percentage were determined for each individual composite sample. Since the values obtained from such composite samples showed very little variation within each place, the surface soil of each place is undoubtedly very homogeneous. To substantiate this conclusion, the values were subjected to an analysis of

Table 54. Chemical properties of the surface soil (A horizon) and subsoil (B horizon) at the five stations.

Station	Horizon	pH	Organic carbon	Organic matter
1	A_1	6.17	0.50	0.84
	A_2	5.51	0.013	0.02
	B_1	5.07	-	-
	B_2	4.91	-	-
2	A_1	5.71	0.58	1.02
	A_2	5.77	0.35	0.62
	B_1	5.61	-	-
	B_2	4.99	-	-
3	A	5.82	0.32	0.54
	B_1	5.94	-	-
	B_2	6.05	-	-
4	A	6.49	1.15	1.98
	B_1	5.65	-	-
	B_2	4.97	-	-
5	A	6.34	0.80	1.37
	B_1	5.76	-	-
	B_2	5.57	-	-

Table 55. Results of mechanical analysis and values of moisture equivalent and of the wilting percentage of the composite soil samples collected by laying out Latin squares.

Station	Percentages of Particles by Diameter-size Classes in Millimeters						
	Total sand 2.0 to 0.05	"Total colloid"	Silt 0.05 to 0.005	Clay 0.005	Fine clay 0.002	Moisture equivalent	Wilting percentage
1	81.72	11.11	10.41	7.86	6.58	5.53	0.78
2	86.48	8.86	7.30	6.22	4.93	4.62	0.84
3	38.56	37.58	30.06	31.37	27.53	21.08	7.36
4	49.10	39.32	20.76	30.14	24.80	19.09	6.33
5	35.08	50.37	22.44	42.48	37.12	23.42	10.36

variance, the results of which showed that neither the variation between rows nor that between the columns of the Latin square was significant. One of the results of analysis of variance is given in Table 56 as an example. In view of such facts, it was decided that only the average values of moisture equivalent and wilting percentage would be presented here (Table 55).

A different arrangement was used for determining the pH and organic matter of the composite samples from the Latin square in each place. The 25 samples from each place were combined into five by mixing five samples from the same row of the Latin square. The results of such determinations are given in Table 57. If the pH values given in this table are compared with those for the surface soil given in Table 54, it will be noticed that they do not agree very well. In some cases, this disagreement in determination of the pH might be attributed to the change of method in collecting the samples. In driving the steel cylinder into the surface soil, and digging it out, the whole sample collected in the sampler was mixed without noticing whether it contained only the soil of A horizon or whether it included also a part of the soil of B horizon. In many instances soils from the B horizon were mixed with the soil of the A horizon, because the A of that place had become so thin as a result of erosion that the cylinder driven into the surface reached the B horizon. Therefore, in such cases the composite samples of the surface soil so collected are not identically the same as those collected from the soil pits. The lower pH of the composite samples from stations 4 and 5 might be explained by this fact, because the B horizon at these two stations is much more acid than the A horizon. The causes of deviations shown by the composite samples from stations 1, 2, and 3 are not clear.

Table 56. Analysis of variance of the moisture equivalent and wilting percentage values of the composite samples collected from the Latin square at Station 5 (Georgeville stony clay, eroded).

For Moisture Equivalent

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between rows	4	75.0698	18.7674	3.55*
Between columns	4	18.1020	4.5255	1.17*
Error	16	84.4710	5.2794	
Total	24	177.6428		

For Wilting percentage

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between rows	4	60.7933	15.1983	2.83*
Between columns	4	17.2595	4.3149	1.25*
Error	16	85.9670	5.3729	
Total	24	164.0198		

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*Not significant.

Table 57. PH values and percentages of organic matter of the composite samples collected by laying out Latin squares.

(1) pH values

Station	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5	Average
1	6.35	6.17	6.08	6.45	6.25	6.24
2	6.11	6.14	6.17	6.12	6.05	6.12
3	5.33	5.40	5.44	5.42	5.36	5.39
4	5.67	5.98	5.80	5.79	5.62	5.75
5	5.76	5.98	5.67	5.66	5.78	5.57

(2) Organic matter

Station	Mixture 1	Mixture 2	Mixture 3	Mixture 4	Mixture 5	Average
1	0.89	0.89	0.85	0.81	0.83	0.85
2	0.88	0.92	0.90	0.88	0.83	0.88
3	0.50	0.54	0.55	0.57	0.55	0.54
4	1.40	1.37	1.49	1.35	1.46	1.41
5	1.47	1.37	1.25	1.38	1.52	1.40

The percentage of organic matter in the composite samples of each place does not show very much deviation from those given in Table 54. From the figures shown in both tables it can be seen that the organic matter content in the surface soil at the five stations is not the same. In order to see whether such differences are significant, the data on organic matter shown in Table 57 were subjected to an analysis of variance which is shown in Table 58. By comparing the means for the five stations with their fiducial limit (ts), it can be seen that the difference in organic matter of the surface soil between stations 1 and 2 and that between stations 4 and 5 is not significant; but all the other differences are significant

Soil Moisture:

Although soil moisture content for all the five stations was determined from May through September, 1937, only the data obtained at stations 1 and 2 are of much interest. These data are shown in Table 59. This table shows that throughout the growing season, the available soil moisture in the plantation, either in the surface soil or in the subsoil, was lower than that in the soil of the open area. This relation is further shown in Figure 10. Another interesting point shown by these data is that the available soil moisture during the dry season was affected more in the subsoil than in the surface soil. This fact seems absurd, but it is not impossible. If the wilting percentages of the surface soil and of the subsoil are compared, it can be seen that the wilting percentage of the former is only about one tenth of that of the latter. This fact shows that more moisture will be available for the plants in the surface soil than in the subsoil. In other words, if both the surface soil and the subsoil hold about the same absolute amount of water, the availability of moisture in the

Table 58. Analysis of variance of the percentages of organic matter in the composite samples collected from the Latin squares at the five stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between Stations	4	2.8659	0.7165	F = 0.7165/0.0105 = 68.24*
Within Stations	20	0.2106	0.0105	
Total	24	3.0765		

ts for between station means = 0.18

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*Highly significant.

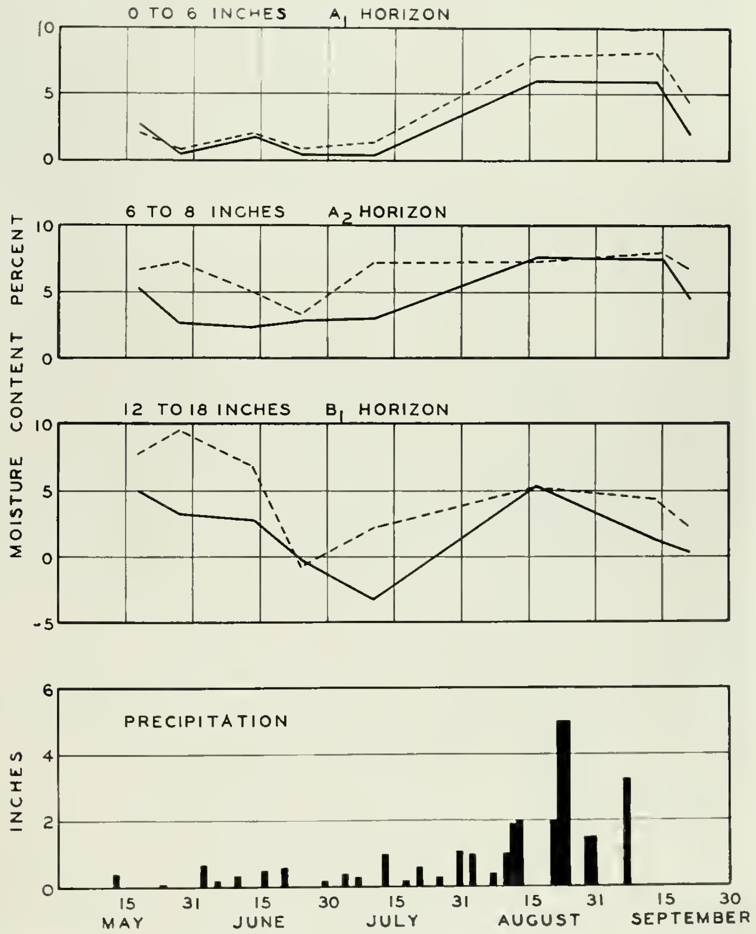

Figure 10. Seasonal trend in 1937 of available soil moisture in the plantation and in the open area. The solid lines represent the plantation, and the broken lines represent the open area.

surface soil will be about ten times that of the subsoil.

Discussion

From the results presented in the foregoing sections it can be seen that inherent differences are present in the three types of soils. Creedmoor sandy loam is a very light textured soil with a lower content of organic matter in the surface soil; Whitestore clay loam is a medium textured soil with very heavy subsoil; and Georgeville stony clay is the heaviest in texture of the three soils, with the highest organic matter content in its surface soil. Such inherent differences, no doubt, are caused by the different parent materials from which the soils are derived. The Creedmoor and Whitestore series are derived from Triassic rocks, such as sandstone, mudstone, and shale, and the Georgeville series is derived from slate of the Carolina slate belt.

The conspicuous physical features of the Creedmoor soil are the relatively higher volume weight of both surface soil and subsoil; the relatively lower water-holding capacity, low moisture equivalent, low wilting percentage; and the considerably high value of the moisture equivalent-wilting percentage ratio of the surface soil.

The Whitestore soil is characterized by low volume weight, high moisture equivalent, high wilting percentage, and a low moisture equivalent-wilting percentage ratio.

The physical features of the Georgeville soil are very much like those of the Whitestore soil. The chemical and physical properties of the Georgeville soil seem not to have been changed by erosion; the only apparent change is the removal of the surface soil.

Another interesting result obtained from the study of the soil

properties is the decrease of the moisture equivalent-wilting percentage ratio with the increase of the "total colloidal" content of the soil. This ratio was presumably held to be a constant for all soils by Briggs and Shantz (1912), but later his conclusion was proved to be erroneous by Veihmeyer and Hendrickson (1934), who found ratios ranging from 1.39 to 3.82, among the more than one hundred soils studied. The ratios of the moisture equivalent to the wilting percentage found in this investigation, from different horizons of different soils, range from 1.6 to 7.1. If these ratios are arranged in a descending order, it can be seen that the "total colloidal" contents of such soils are increasing gradually. This relationship is shown in Table 60. The relation between these two values calculated from Table 60 can be expressed by the following equation:

$$\log Y = 0.74666 - 0.00666 X$$

in which Y is the value of the moisture equivalent-wilting percentage ratio, and X is the "total colloidal" content in percent.

Although the plantation studied might be considered too young to have any significant effect in changing the soil properties, evidence of soil change is not entirely lacking. If the air capacity of the surface soil in the open area (station 1) is compared with that in the plantation (station 2) a difference can readily be found. Air capacity of the surface soil in the plantation is almost twice as high as that in the open area (Table 53). The higher air capacity shown by the soil in the plantation is undoubtedly due to the activity of the tree roots. A similar result has been reported by Auten (1933a) who found that the soil in a plantation absorbed more water than that in an adjacent field. This fact proves that the soil under a forest cover is more porous than that in an open field.

Table 60. Relation of the moisture equivalent-wilting percentage ratio with "total colloid" content (Bouyoucos method) of the soil.

Percentage of "Total colloid"	Moisture equivalent divided by wilting percentage	Calculated ratio
8.9	5.5	4.87
11.1	7.1	4.71
17.0	7.0	4.30
23.2	4.3	3.91
35.9	2.6	3.22
39.3	3.0	3.05
40.7	2.2	2.99
48.9	2.4	2.64
59.4	1.9	2.24
72.9	1.7	1.83
83.5	1.6	1.55

The effect of the plantation on soil moisture is another interesting relationship shown by this investigation. It has been shown by many investigators (Ebermayer, 1889; Fuller, 1914; Halden, 1926; and Craib, 1929) that soils under forest cover contained much less moisture than that in the open. The data presented in Table 59 agree completely with such statements. According to the data shown in Table 59 it can be seen that in the first 6 inches of the surface soil, the difference in soil moisture, in the plantation and in the open area, was not as high as that below 6 inches. Although little of the surface soil moisture in the open area is lost through transpiration, a considerably quantity of it may be lost through evaporation, because the evaporation rate in the open area is much higher than that in the plantation. The high evaporation rate in the open area has the same effect as transpiration of forest trees in reducing surface soil moisture. This fact will explain why the difference in surface soil moisture between the two places was not as significant as that in the subsoil.

STUDIES OF TREE GROWTH

Methods of Study

The growth condition of trees in the plantations was studied from two aspects: (1) roots and (2) diameter and height of stem. When the soil profiles were mapped, as described in a previous section, the vertical distribution of roots in the profile was also charted. Roots were charted on cross-section paper, using symbols to denote the various size classes recognized, which were: 0 to 0.05 inch, 0.051 to 0.10 inch, 0.11 to 0.20 inch, 0.21 to 0.30 inch, 0.31 to 0.40 inch, 0.41 to 0.5 inch, and 0.51 to 1.00 inch. However, in enumerating the number of roots in each horizon, only four diameter-size classes were recognized; namely, 0.0 to 0.10 inch, 0.11 to 0.30 inch, 0.31 to 0.50 inch, and 0.51 to 1.00 inch.

The height of the tree was measured to the nearest half foot with an extensible measuring rod marked at half-foot intervals. The diameter of the tree was measured to the nearest 0.1 inch with a diameter tape at breast height (4.5 feet from the ground). The method of sampling trees to be measured is described below:

In each plantation six plots were chosen so that three of them

were located on the uneroded soil, and three of them were on the eroded soil. Each plot covered an area which comprised ten rows with ten trees in each row. The soil character was held as the only criteria for choosing the location of the plot in the plantations. In each plantation every plot on the eroded soil was paired with another on the uneroded soil by placing them as close together as possible, while the distnances of such pairs were kept as great as possible. Out of the ten rows, four were chosen at random by using Tippett's random sampling numbers (Tippett, 1927). By the same method, five trees were chosen from each row and their height and diameter measured. At the same time the depth of the surface soil (A horizon) was determined with a soil auger at a spot 3 feet from the tree. All the measurements were made in December, 1937. In the analysis of variance of the results the average of the measurements of 20 trees from each plot was used as a single observation.

Results:

Table 61 gives the total number of roots and the number per square foot by diameter-size classes, in the various soil horizons in the eroded and uneroded soils in the two plantations. This table shows clearly that the roots were mainly concentrated in the upper few inches of the surface soil. Density (number per square foot), as well as total number, of roots is much greater in the upper horizon than in the lower horizon. For example, at station 2, the area of the A_1 horizon is only 17.8 percent of the total area of the profile, but it has 56.3 percent of the total number of roots. Density of roots in the A_1 horizon is 24.06 per square foot, while that in the A_2 horizon is only 7.1 per square foot, with 20.2 percent of the total area of the profile. This table also shows that roots are

Table 61. Vertical root distribution in the profile (sum of 4 profiles).

Horizon	Area		Number of roots per square foot					Percentages of roots in the total area of the profile
	Square foot	Per cent	Diameter-size classes (inches)				Total	
			0.-0.1	0.11-0.3	0.31-0.5	0.5-1.0		
Station 2. Creedmoor loamy sand								
A_1	8.58	17.8	21.3 (183)*	2.4 (21)	0.23 (2)	0.13 (1)	24.1 (207)	56.4
A_2	9.72	20.2	5.1 (50)	2.0 (19)	-	-	7.1 (69)	18.8
B_1	20.10	41.7	3.4 (68)	0.65 (13)	0.05 (1)	-	4.1 (82)	22.3
B_2	9.75	20.3	0.92 (9)	-	-	-	0.92	2.5
Station 3. Whitestore clay loam (eroded)								
A	6.32	14.0	3.6 (23)	1.7 (11)	0.16 (1)	-	5.5 (35)	43.2
B	38.68	86.0	1.1 (44)	0.05 (2)	-	-	1.2 (46)	56.8
Station 4. Georgeville stony clay (not eroded)								
A	9.32	15.5	9.1 (85)	2.4 (22)	0.43 (4)	-	11.9 (111)	59.0
B_1	23.66	39.2	2.2 (52)	0.46 (11)	0.04 (1)	-	2.7 (64)	34.0
B_2	27.33	46.3	0.4 (11)	0.07 (2)	-	-	0.47 (13)	7.0
Station 5. Georgeville stony clay (eroded)								
A	3.88	13.5	7.5 (29)	1.0 (4)	-	-	8.5 (33)	55.0
B	24.92	86.5	0.8 (20)	0.28 (7)	-	-	1.1 (27)	45.0

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*Figures in parenthesis are the total number of roots.

most numerous in the light textured soil, (Creedmoor sandy loam), and much less numerous in the heavy textured soil (Georgeville stony clay). If the number of roots in the eroded soil is compared with that in the uneroded soil, it can be seen that root development was much hindered in the eroded soil. The result of root distribution in the soil profile found by the writer is generally in agreement with such observations as made by Coile (1937), Lutz, and others (1937), and Korstian and Coile (1938). Coile found most of the fine roots near the surface in the A horizon; in the C horizon very few fine roots occurred. Lutz and his associates also found that the number of roots per square foot of cross-sectional area in the mineral soil horizons decreased with increasing depth below the surface.

Table 62 gives the average height and diameter of 20 trees measured in each of the six plots located on eroded and uneroded soils in the two plantations. In the same table is also shown the average depth of the surface soil (A horizon). From this table it can be seen that tree growth was very poor on the eroded soil. The data on average height and diameter were subjected to an analysis of variance with the results shown in Tables 63 and 64. Table 63 shows that the average height of trees in the four places is highly significant, with an observed F of 37.49, whereas F at the 1 percent level is only 7.59. Table 64 shows the same conclusion with the average diameter of the trees, with an observed F of 34.96. If the individual differences between pairs of the mean height and of the mean diameter of tree in the four places are compared with their corresponding fiducial limits (ts), as shown in Table 65, it can be seen that not all the differences are significant. From Table 65, it is very evident that the differences in height and in diameter between the trees grown on the eroded soil and those on the uneroded soil, either of the same or of different

Table 62. Average height in feet and average diameter in inches of 20 trees measured in each of the three plots located at the four stations in the two plantations.

Plot No.		Station 2	Station 3	Station 4	Station 5
1	Height	15.9	10.8	14.9	5.7
	Diameter	3.14	1.75	2.71	0.39
	Depth of A horizon (inches)	10.15	6.80	4.50	0
2	Height	19.3	9.8	16.2	8.4
	Diameter	4.00	1.62	2.95	1.10
	Depth of A horizon (inches)	10.40	3.70	7.30	1.50
3	Height	16.0	11.1	14.8	8.7
	Diameter	3.22	1.98	2.82	1.12
	Depth of A horizon (inches)	5.45	3.80	4.40	0
Average	Height	17.1	10.6	15.3	7.6
	Diameter	3.45	1.78	2.83	0.87
	Depth of A horizon (inches)	8.6	4.4	5.4	0.5

Table 63. Analysis of variance of average height of 20 trees in the four stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	3	168.70	56.23	37.49*
Within stations	8	12.04	1.50	
Total	11	180.74		

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*Highly significant.

Table 64. Analysis of variance of average diameter of 20 trees at the four stations.

Source of variation	Degrees of freedom	Sum of squares	Mean squares	Observed F
Between stations	3	11.7049	2.9016	34.96*
Within stations	8	0.8926	0.1116	
Total	11	12.5975		

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*Highly significant.

Table 65. Comparison of mean height in feet and mean diameter in inches of the trees at the four stations.

	Station 2	Station 3	Station 4	Station 5	ts	
Diameter	3.45	1.78	2.83	0.87	0.92*	0.63**
Height	17.1	10.6	15.3	7.6	3.4*	2.3**

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*At 1 percent level.
**At 5 percent level.

soil types, are significant. The differences in average height and in average height and in average diameter between the trees growing on two different soil types which were not eroded, are not significant. The differences in average height and in average diameter between trees growing on different soil types which were eroded, are significant. The significant difference shown by the trees growing on the two different eroded soil types may be explained by the different degree of erosion suffered by the two types of soil. As indicated by the average depth of the surface soil, the Whitestore soil was not eroded so severely as the Georgeville soil, from which the surface soil was almost entirely gone. Coile (1935) reported that the quotient obtained by dividing the silt and clay content, or the colloidal content, in percent, of the B_1 horizon by the average depth in inches below the surface at which that horizon is encountered was a reliable measure of site quality for shortleaf pine. If this quotient is calculated for the soils studied and is compared with the average height and diameter of trees, it will be seen that a similar relation exists. The height and diameter are inversely proportional to this quotient, as shown in Table 66.

Table 66. The relation of average height in feet and diameter in inches with the "texture-depth index."

Average height	17.1	10.6	15.3	7.6
Average diameter	3.45	1.78	2.83	0.87
Silt-clay-depth index	5.4	17.0	15.3	176.9
Colloid-depth index	4.7	13.5	11.3	167.0

STUDIES OF LESSER VEGETATION

In order to determine the effect of erosion on the lesser vegetation in the plantations, quadrat counts were made in October, 1937. This was done according to the following scheme: In each plantation, eight plots were chosen, four of which were on eroded soil and four on normal soil. Sizes of the plots vary, but they were not less than 30 by 30 feet. The plots on eroded and uneroded soils were always so selected that they were located as close to each other as possible. For quadrat count, 10 quadrats with a size of one-fortieth milacre were selected at random in each plot. Names of species and number of individuals for each species in each quadrat were noted and counted in the field. The four sets of quadrat counts with four plots each are summarized in Table 67. Under each species two figures are given, one for the total number of individuals and one for the frequency, in this case the number of quadrats in which the species occurred.

Although the floristic composition between the plots on eroded and uneroded soils does not differ much, the number of individuals and frequency of species are very different under the two different soil conditions. The contrast of the lesser vegetation on the eroded and uneroded soils can

Table 67. List of plants found in the two plantations, counted from 40 1/40 milacre quadrats.

Species	Location 1				Location 2			
	Uneroded soil		Eroded soil		Uneroded soil		Eroded soil	
	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency
Acalypha gracilens A Gray	-	-	-	-	5	2	1	1
Ambrosia patens	-	-	-	-	-	-	1	1
Andropogon scoparius Michx.	24	7	39	15	65	22	141	25
Andropogon virginicus L.	9	2	32	6	-	-	-	-
Aristida dichotoma	1	1	2256	28	-	-	755	13
Aristida oligantha	-	-	6	1	-	-	19	7
Aster ericoides	1	1	1	1	1	1	-	-
Chamaecrista nictitans Moench.	4	4	3	3	2	2	3	3
Chrysopsis mariana	-	-	1	1	-	-	-	-
Danthonia spicata (L.) Beaux	-	-	6	3	6	3	8	4

Table 67. (Continued)

Species	Location 1				Location 2			
	Uneroded soil		Eroded soil		Uneroded soil		Eroded soil	
	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency
Daucus carota	1	1	-	-	5	4	4	3
Digitaria filiformis	-	-	-	-	1	1	-	-
Diodia teres	1	1	-	-	-	-	-	-
Eragrotis spectabilis	1	1	-	-	1	1	-	-
Eupatorium capillifolium	1	1	-	-	-	-	-	-
Eupatorium hyssopifolium	1	1	-	-	-	-	-	-
Fragaria virginiana Duchense	7	2	-	-	-	-	-	-
Gnaphalium obtusifolium	2	2	2	2	-	-	-	-
Gymnopogon ambiguus	1	1	4	2	15	10	11	6

Table 67. (Continued)

Species	Location 1				Location 2			
	Uneroded soil		Eroded soil		Uneroded soil		Eroded soil	
	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency
Ipomoea pandurata	-	-	-	-	-	-	1	1
Juncus effusus	3	3	-	-	-	-	-	-
Juncus tenuis	2	1	2	1	-	-	1	1
Lespedeza repens (L.) Bart.	-	-	-	-	3	3	4	3
Lespedeza striata (Thunb.) H. et A.	-	-	54	6	-	-	413	16
Lespedeza virginica (L.) Brit.	-	-	-	-	-	-	4	3
Muhlenbergia schreberi	1	1	-	-	-	-	-	-
Oenothera fruticosa	2	2	8	4	-	-	-	-
Panicum sphaerocarpon Ell.	-	-	7	4	19	16	7	4
Plantago aristata	-	-	22	3	-	-	-	-

Table 67. (Continued)

Species	Location 1				Location 2			
	Uneroded soil		Eroded soil		Uneroded soil		Eroded soil	
	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency
Potentilla canadensis	-	-	3	2	-	-	-	-
Potentilla pumila Poir.	15	7	12	2	28	18	14	5
Prunella vulgaris L.	-	-	-	-	1	1	-	-
Rhus typhina	1	1	-	-	-	-	1	1
Rubus procumbens	5	5	1	1	21	15	3	3
Scleria sp.	1	1	-	-	-	-	-	-
Senecio smallii Britton	1	1	-	-	-	-	2	2
Solidago juncea Ait.	5	3	64	17	5	4	48	20
Solidago minor	-	-	-	-	1	1	-	-
Solidago nemoralis Ait.	17	7	54	17	10	9	8	6

Table 67 (Continued)

Species	Location 1				Location 2			
	Uneroded soil		Eroded soil		Uneroded soil		Eroded soil	
	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency	Number of individuals	Frequency
Solidago serotina	2	2	31	6	3	1	-	-
Sorghastrum nutans	-	-	-	-	13	5	1	1
Tecoma radicans	7	6	11	9	-	-	-	-
Total	116	65	2613	131	205	109	1450	129
Total number of species	26		21		19		22	
Number of individuals per species	4.5		124.4		10.8		65.9	
Specific density	1.8		19.9		1.9		11.2	

be seen more clearly when phytographs are compared (Figure 11). The radii used for construction of these phytographs are as follows:

1. Total Number of Individuals (Radius ON): The actual number of individuals counted in the 40 quadrats for each set of the four plots.

2. Total Frequency (Radius OF): The total number of quadrats in which the species occurred, by count, in the 40 quadrats in each set of the four plots.

3. Number of Individuals per Species (Radius OS): The total number of individuals divided by the number of species of the same set of four plots.

4. Specific Density (Radius OD): The total number of individuals divided by the total frequency.

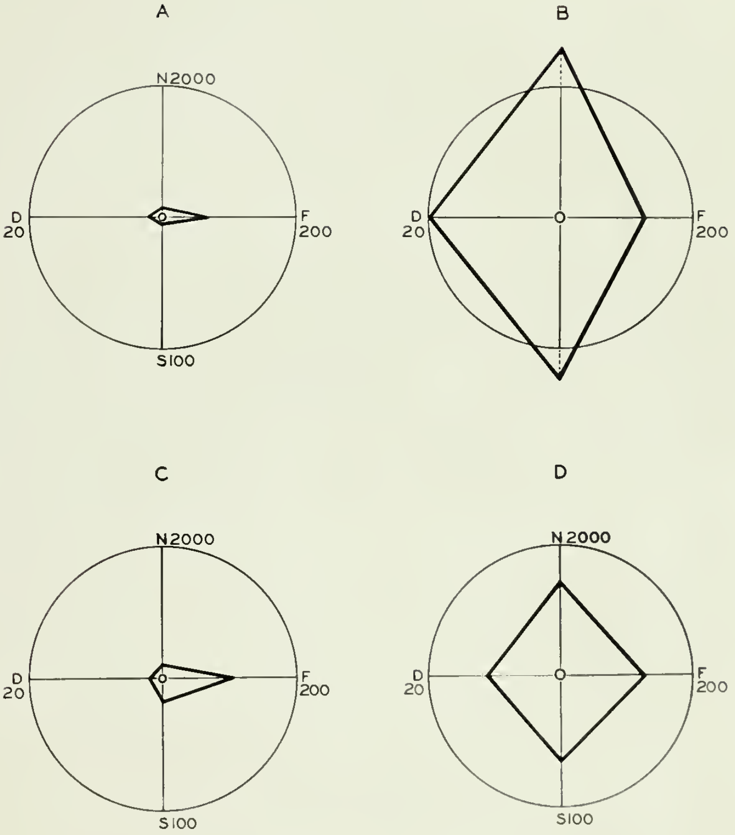

Figure 11. Phytographs for the four sets of plots located on different soils. (A) On Creedmoor sandy loam uneroded, (B) On Whitestore clay loam eroded, (C) On Georgeville stony clay uneroded, and (D) On Georgeville stony clay eroded.

SUMMARY AND CONCLUSIONS

The interaction of site factors in young loblolly pine plantations was investigated in the Durham Division of the Duke Forest near Durham, North Carolina, during 1936 and 1937. The investigation included two parts: (1) Study of the effect of the plantation on the microclimatic and soil factors; (2) Study of the effect of different soil conditions on tree growth and lesser vegetation. The results obtained from such observations are presented in the paragraphs that follow:

1. Air temperatures, including mean, maximum, and minimum, were found to be higher in the plantation than in the open area, with an annual difference of 1.58 degrees F. for the mean, 2.31 degrees F. for the maximum, and 1.91 degrees F. for the minimum temperatures. The greatest differences were found in the summer, with a value of 2.01 degrees F. for the mean, 2.80 degrees F. for the maximum, and 2.24 degrees F. for the minimum temperatures. There was not much difference in range between the maximum and minimum temperatures for the two stations.

2. Relative humidity was found to be higher in the plantation than in the open area. The difference occurred mainly during the day.

The greatest difference was found to be in the summer and spring seasons. The minimum relative humidity was lower in the open area than in the plantation. The difference in vapor pressure deficit between the two stations was found to be not significant.

3. The rainfall recorded at the two stations did not agree very well. When the rain fell in small volume, the rainfall recorded inside the plantations was higher than in the open area, but when it fell in large volume, the amount recorded was lower inside the plantation than in the open area. In the summer the rainfall recorded was 4.1 inches less in the plantation than in the open area.

4. Air movement was considerably less in the plantation than in the open area. The total air movement recorded by the anemometer inside the plantation was only 6.8 percent of that in the open area, during the period of one year.

5. The evaporation rate was found to be very much lower in the plantation than in the open area. The annual evaporation near the soil surface in the plantation was only 34.5 percent of that in the open area, and that at a height of 6 feet in the plantation was only 23 percent of that in the open area. The difference in annual evaporation between the two positions in the plantation was found not significant. In the open area, the evaporation near the soil surface was only 46.55 percent of that at a height of 6 feet.

6. It was found that there was no significant difference in the effect of microclimatic factors on the evaporation rate at the two stations. Mean and mean maximum vapor pressure deficits were the significant factors of quantitative importance in affecting the evaporation rate in the plantation, but in the open area maximum air temperature and air movement were the significant factors.

7. Air movement was thought to be the only factor of any significance in causing the difference in evaporation between the two stations and between the two positions at the same station.

8. Surface soil temperature and soil temperature at a depth of 6 inches, including mean, maximum, and minimum, were found to be higher in the open area than in the plantation. The annual differences at the soil surface between the two stations were 2.90 degrees F. for the mean, 6.93 degrees F. for maximum, and 0.32 degree F. for the minimum, and those at 6-inch depth were 3.46 degrees F. for the mean, 4.83 degrees F. for the maximum, and 2.05 degrees F. for the minimum. At both stations the surface soil temperature was higher than that at 6-inch depth. This difference between the two depths was greater in the plantation than in the open area. At both depths the range between the maximum and minimum soil temperatures was greater in the open area than in the plantation.

9. Air capacity of the surface soil of the plantation was found to be higher than that of the unplanted area. Its organic matter content was also higher but the difference was not significant. During the growing season, the available soil moisture, both in the surface soil and in the subsoil, was much less in the plantation than in the open area.

10. Studies on soil properties showed that Creedmoor sandy loam had a greater volume weight and lower moisture equivalent than the other two soil types (Whitestore clay loam, and Georgeville stony clay). Wilting percentage and water holding capacity of the latter soil types were higher than in the Creedmoor soil.

11. The ratio of the moisture equivalent to wilting percentage was found to be directly proportional to the "total colloidal" content of the soil as determined by Bouyoucos method. The relation between these two quantities may be expressed by the following equation:

$$\log Y = 0.74666 - 0.0666 X$$

in which Y is the ratio of moisture equivalent to the wilting percentage, and X is the "total colloidal" content in percent.

12. There was no significant difference in height and diameter growth of trees growing on the two uneroded soil types, namely, Creedmoor sandy loam, and Georgeville stony clay. Significant differences in height and diameter were found only in trees growing on eroded and uneroded soils. Trees growing on uneroded soils had greater height and larger diameter than those on the eroded soil.

13. Height and diameter growth was found to be proportional to the average depth of the surface soil. Trees grow best on soil with the deepest surface soil.

14. By examining the vertical root distribution in the soil profile, it was found that the best development of root was limited to the first 6 inches below the surface. The number of roots per square foot decreased with increase in depth below the surface.

15. Light soil texture was found to be more favorable for root development than heavy soil texture.

16. Quantitatively speaking the lesser vegetation on eroded soils was very different from that on the uneroded soils. The number of individuals per species and the specific density of the lesser vegetation were much higher on the eroded soils than on the uneroded soils.

17. As a general conclusion it can be said that the microclimate in a young plantation is definitely different from that in an open area. The modifying effects of a plantation on the microclimatic factors are shown by the rise of air temperature, reduction in evaporation, retardation of air movement, and decrease in soil temperature. Changes in soil condition in a young plantation are very slight and are not significant. In

regard to the effects of the soil conditions on the development of a young plantation, as shown by this investigation, erosion seems to be the most important factor. Both Georgeville stony clay and Creedmoor sandy loam are suitable for loblolly pine planting if the soil is not eroded, but neither of them will support good tree growth, if the soil is severely eroded.

APPENDIX

Table 68. Mean weekly values for air temperature in degrees F. at the two stations.

Date		In the plantation			In the open area		
		Mean	Maximum	Minimum	Mean	Maximum	Minimum
1936	9-7 9-13	69.04	83.23	57.03	67.25	80.43	55.43
	9-28 10-4	67.08	79.50	58.17	64.26	75.50	54.17
	10-5 10-11	70.24	78.67	60.93	67.03	77.17	58.33
	10-12 10-18	62.38	74.25	52.68	61.35	73.00	50.43
	10-19 10-25	60.42	77.71	47.97	59.42	76.14	46.14
	10-26 11-1	49.44	63.86	38.29	48.08	61.43	35.71
	11-2 11-8	58.68	68.71	49.71	57.27	67.29	48.00
	11-9 11-15	48.42	61.14	37.57	47.31	59.43	35.86
	11-16 11-22	42.16	59.00	28.71	40.69	57.14	26.14
	11-23 11-29	39.65	53.29	28.14	38.07	51.00	25.57
	11-30 12-6	39.81	49.29	32.71	38.64	47.14	31.29
	12-7 12-13	41.69	48.43	34.95	40.51	47.43	34.00
	12-14 12-20	41.07	48.43	35.57	40.45	48.14	34.29
	12-21 12-27	38.80	58.00	26.00	38.06	57.71	24.14
1937	12-28 1-3	49.92	54.71	45.86	49.50	53.71	43.86

Table 68. (Continued)

Date	In the plantation			In the open area		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
1-4 1-10	50.25	55.61	43.79	49.06	54.86	42.29
1-11 1-17	50.56	56.17	45.14	49.81	55.00	44.14
1-18 1-24	51.59	60.29	43.71	50.51	60.00	42.00
1-25 1-31	43.94	48.86	38.29	43.08	48.00	36.71
2-1 2-7	37.76	47.57	29.14	37.29	46.86	28.29
2-8 2-14	45.42	57.14	33.29	43.93	55.29	31.57
2-15 2-21	41.74	49.43	35.29	41.71	48.93	33.95
2-22 2-28	36.27	48.29	23.29	34.77	46.29	21.62
3-1 3-7	44.06	61.57	27.14	42.84	58.24	26.31
3-8 3-14	45.44	59.71	33.14	42.80	55.51	30.34
3-15 3-21	45.25	58.14	34.00	42.61	53.94	31.20
3-22 3-28	50.14	65.14	36.71	47.95	60.47	33.71
3-29 4-4	50.83	68.00	34.86	48.64	63.33	31.86
4-5 4-11	53.99	65.14	44.14	51.89	61.94	42.14
4-12 4-18	56.13	73.86	39.43	54.37	71.76	37.83

Table 68. (Continued)

Date	In the plantation			In the open area		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
4-19 4-25	61.96	72.86	52.29	60.54	71.86	51.09
4-26 5-2	53.74	66.86	40.86	52.53	65.36	39.66
5-3 5-9	59.88	77.57	45.00	58.88	75.57	45.00
5-10 5-16	65.09	78.29	52.29	63.99	75.57	50.57
5-17 5-23	69.13	87.14	52.14	67.54	83.43	50.43
5-24 5-30	74.40	91.14	60.71	72.62	87.29	59.43
5-31 6-6	77.44	94.14	64.71	75.98	91.14	63.14
6-7 6-13	74.69	89.43	63.14	73.21	86.57	62.00
6-14 6-20	75.95	90.86	66.86	74.27	88.00	65.14
6-21 6-27	76.89	92.14	63.71	74.55	87.71	61.43
6-28 7-4	72.88	89.71	61.57	70.68	84.71	58.71
7-5 7-11	78.61	93-57	67.43	76.67	90.00	65.43
7-12 7-18	82.81	99.43	71.00	81.04	94.43	69.29
7-19 7-25	73.30	84.14	63.14	70.33	81.00	61.00
7-26 8-1	75.60	88.71	66.14	72.33	85.57	63.57

Table 68. (Continued)

Date	In the plantation			In the open area		
	Mean	Maximum	Minimum	Mean	Maximum	Minimum
8-2 8-8	76.19	90.43	66.14	74.55	88.14	63.86
8-9 8-15	75.76	87.86	68.57	74.18	85.86	66.00
8-16 8-22	76.79	90.57	66.57	74.85	88.00	64.14
8-23 8-29	75.47	84.36	70.86	73.69	83.86	68.86
8-30 9-5	77.00	88.14	69.67	75.67	87.43	67.43
9-6 9-12	69.24	76.57	63.86	67.48	75.14	61.57
9-13 9-19	64.44	78.00	53.71	61.83	75.33	51.83

Table 69. Mean weekly percentage values for relative humidity at the two stations.

Date		In the plantation			In the open area		
		Mean Rel.Hum.		Minimum Relative Humidity	Mean Rel. Hum.		Minimum Relative Humidity
		Day	Night		Day	Night	
1936	9-21 9-27	70.90	96.55	51.29	71.43	96.36	48.71
	9-28 10-4	77.83	98.38	60.86	77.64	99.05	62.71
	10-5 10-11	84.31	100.00	64.71	81.45	100.00	61.71
	10-12 10-18	68.49	95.63	51.36	63.74	94.71	46.86
	10-19 10-25	71.95	100.00	43.14	65.98	100.00	39.43
	10-26 11-1	67.76	92.50	43.83	61.74	90.72	39.00
	11-2 11-8	78.05	95.90	60.29	76.78	95.76	60.29
	11-9 11-15	65.57	95.62	43.43	57.74	91.81	36.57
	11-16 11-22	53.71	78.83	32.86	47.24	75.95	27.00
	11-23 11-29	60.48	89.45	38.30	54.38	86.33	33.29
	11-30 12-6	77.55	92.52	67.14	73.57	89.86	61.29
	12-7 12-13	91.52	91.41	81.14	91.29	90.72	79.71
	12-14 12-20	78.50	91.83	57.00	73.81	91.24	52.00
	12-21 12-27	61.55	97.74	33.57	55.36	96.78	27.43

Table 69. (Continued)

Date		In the plantation			In the open area		
		Mean Rel.Hum.		Minimum Relative Humidity	Mean Rel.Hum.		Minimum Relative Humidity
		Day	Night		Day	Night	
	12-28 1-3	90.95	98.05	78.57	89.40	97.31	74.86
1937	1-4 1-10	91.04	96.71	77.79	87.76	94.74	71.29
	1-11 1-17	91.74	95.76	80.47	90.55	94.48	78.14
	1-18 1-24	92.33	100.00	82.43	91.10	100.00	80.57
	1-25 1-31	80.43	88.14	65.71	79.17	86.98	63.86
	2-1 2-7	59.86	82.95	37.86	54.44	77.48	32.69
	2-8 2-14	68.81	93.83	46.29	63.41	91.07	38.14
	2-15 2-21	71.00	89.98	58.86	68.19	85.72	56.03
	2-22 2-28	51.93	81.52	37.14	46.44	78.51	29.89
	3-1 3-7	47.45	91.31	29.00	43.58	87.20	29.16
	3-8 3-14	61.81	88.48	40.86	57.13	85.09	40.06
	3-15 3-21	72.14	94.90	60.67	69.07	86.14	57.75
	3-22 3-28	51.67	80.14	36.00	46.21	77.18	28.97
	3-29 4-4	44.38	83.83	24.57	36.63	79.88	20.32

Table 69. (Continued)

Date	In the plantation			In the open area		
	Mean Rel.Hum.		Minimum Relative Humidity	Mean Rel.Hum.		Minimum Relative Humidity
	Day	Night		Day	Night	
4-5 4-11	65.63	90.06	49.20	61.40	87.64	45.40
4-12 4-18	45.40	82.29	30.71	37.47	78.41	25.40
4-19 4-25	64.38	89.55	51.57	60.75	86.55	50.17
4-26 5-2	56.76	94.93	42.71	53.08	91.48	42.45
5-3 5-9	49.57	98.62	33.71	45.94	94.75	34.21
5-10 5-16	59.67	92.50	40.29	55.34	89.50	39.00
5-17 5-23	44.81	91.93	32.14	41.50	86.81	32.14
5-24 5-30	53.24	98.62	38.43	47.17	91.38	36.71
5-31 6-6	60.19	96.62	45.14	54.21	90.43	39.71
6-7 6-13	60.40	98.98	43.29	53.83	96.24	41.86
6-14 6-20	72.48	97.59	49.43	63.78	95.95	45.86
6-21 6-27	54.24	96.83	39.29	50.31	90.19	39.57
6-28 7-4	60.95	96.48	40.29	54.93	91.83	40.29
7-5 7-11	68.08	99.19	47.86	58.81	97.55	45.00

Table 69. (Continued)

Date	In the plantation			In the open area		
	Mean Rel.Hum.		Minimum Relative Humidity	Mean Rel.Hum.		Minimum Relative Humidity
	Day	Night		Day	Night	
7-12 7-18	60.05	97.93	42.86	55.17	92.79	41.86
7-19 7-25	70.88	97.00	54.00	64.38	92.60	50.00
7-26 8-1	71.40	99.41	47.00	66.00	98.55	46.29
8-2 8-8	74.97	100.00	50.71	70.60	100.00	52.00
8-9 8-15	79.86	99.76	57.43	75.79	99.69	56.29
8-16 8-22	73.79	100.00	53.57	68.83	100.00	53.00
8-23 8-29	89.63	100.00	71.97	84.24	100.00	62.14
8-30 9-5	80.45	97.57	59.43	74.74	100.00	56.14
9-6 9-12	83.24	96.93	68.57	79.21	98.07	66.14
9-13 9-19	68.26	96.83	47.00	61.28	94.93	45.00

Table 70. Mean weekly values for vapor pressure deficit in millimeters of mercury at the two stations.

Date	In the plantation			In the open area		
	Mean vapor pressure deficit		Maximum vapor pressure deficit	Mean vapor pressure deficit		Maximum vapor pressure deficit
	Day	Night		Day	Night	
1936 9-21 9-27	8.46	1.68	15.23	7.12	0.54	13.87
9-28 10-4	4.94	0.14	9.63	4.73	0.13	8.32
10-5 10-11	3.88	0	8.64	3.85	0	8.41
10-12 10-18	6.06	0.58	10.39	6.72	0.64	10.81
10-19 10-25	5.84	0	13.70	6.89	0	13.84
10-26 11-1	4.09	0.56	8.85	4.56	0.65	8.55
11-2 11-8	3.69	0.36	7.57	3.78	0.34	7.27
11-9 11-15	4.03	0.41	7.75	4.71	0.71	8.27
11-16 11-22	4.78	1.52	8.64	5.24	1.64	8.96
11-23 11-29	3.38	0.68	6.31	3.66	0.84	6.38
11-30 12.6	1.68	0.35	3.23	1.92	0.44	3.31
12-7 12-13	0.44	0.55	1.47	0.52	0.46	1.38
12-14 12-20	1.78	0.54	4.02	2.16	0.56	4.68
12-21 12-27	3.81	0.11	8.18	4.44	0.15	8.75

Table 70. (Continued)

Date	In the plantation			In the open area		
	Mean vapor pressure deficit		Maximum vapor pressure deficit	Mean vapor pressure deficit		Maximum vapor pressure deficit
	Day	Night		Day	Night	
1937 12-28 1-3	0.89	0	2.07	0.97	0.24	2.47
1-4 1-10	0.89	0.29	2.36	1.13	0.37	2.93
1-11 1-17	0.94	0.46	2.51	1.02	0.49	2.70
1-16 1-24	1.47	0	3.70	1.66	0	4.00
1-25 1-31	1.52	0.79	2.69	1.55	0.88	2.71
2-1 2.7	2.73	0.89	4.12	3.10	1.16	5.37
2-8 2-14	3.15	0.46	6.30	3.45	0.54	6.81
2-15 2-21	2.28	0.62	3.96	2.40	0.85	3.91
2-22 2-28	3.25	1.02	6.16	3.36	1.21	6.21
3-1 3-7	6.60	0.80	10.23	6.23	1.04	8.97
3-8 3-14	4.72	0.96	8.67	4.54	1.09	7.30
3-15 3-21	3.68	0.30	6.35	3.54	0.34	5.35
3-22 3-28	6.48	1.51	10.54	6.21	1.72	9.23
3-29 4-4	8.63	1.39	14.00	8.27	1.58	12.36

Table 70. (Continued)

Date	In the plantation			In the open area		
	Mean vapor pressure deficit		Maximum vapor pressure deficit	Mean vapor pressure deficit		Maximum vapor pressure deficit
	Day	Night		Day	Night	
4-5 4-11	4.09	0.74	7.28	4.59	0.99	7.63
4-12 4-18	9.72	2.59	15.24	8.66	3.47	16.34
4-19 4-25	7.85	1.76	12.05	7.82	2.15	11.24
4-26 5-2	6.97	0.50	10.62	6.94	0.61	10.17
5-3 5-9	10.16	0.17	15.22	10.49	0.57	14.57
5-10 5-16	9.14	1.16	15.15	9.27	1.46	14.32
5-17 5-23	15.22	1.45	21.86	14.73	2.10	19.71
5-24 5-30	14.59	0.27	22.65	14.83	1.54	20.65
5-31 6-6	14.00	0.82	23.96	14.50	1.95	22.48
6-7 6-13	12.79	0.26	19.86	12.99	0.78	18.63
6-14 6-20	9.12	0.37	18.79	10.64	0.63	18.47
6-21 6-27	15.17	0.66	23.26	14.53	1.98	19.92
6-28 7-4	11.91	0.68	21.57	11.98	1.51	18.31
7-5 7-11	13.31	0.24	23.04	14.18	0.57	20.65

Table 70. (Continued)

Date	In the plantation			In the open area		
	Mean vapor pressure deficit		Maximum vapor pressure deficit	Mean vapor pressure deficit		Maximum vapor pressure deficit
	Day	Night		Day	Night	
7-12 7-18	16.64	0.61	29.28	16.47	1.85	24.17
7-19 7-25	8.50	0.71	15.39	9.67	1.63	14.95
7-26 8-1	8.73	0.15	18.93	9.35	0.35	17.09
8-2 8-8	8.20	0	17.82	8.80	0	16.28
8-9 8-15	6.25	0.06	14.23	6.89	0.08	13.81
8-16 8-22	8.60	0	16.83	9.23	0	15.43
8-23 8-29	2.01	0	8.57	4.31	0	11.21
8-30 9-5	6.00	0.31	13.46	7.75	0	14.46
9-6 9-12	3.88	0.30	7.96	4.31	0.32	8.31
9-13 9-19	7.02	0.24	13.79	7.70	0.68	12.62

Table 71. Weekly records of precipitation in number of inches at the two stations.

Date		In the plantation	In the open area
1936	9-21 9-27	0.38	0.29
	9-28 10-4	1.63	1.33
	10-5 10-11	2.16	1.51
	10-12 10-18	0.83	1.22
	10-18 10-25	0	0
	10-26 11-1	0	0
	11-2 11-8	0.42	0.56
	11-9 11-15	1.13	1.09
	11-16 11-22	0	0
	11-23 11-29	0	0
	11-30 12-6	1.84	1.73
	12-7 12-13	2.21	2.08
	12-14 12-20	1.11	1.02
	12-21 12-27	0	0
1937	12-28 1-3	3.41	2.94
	1-4 1-10	1.19	1.08

Table 71. (Continued)

Date	In the plantation	In the open area
1-11 1-17	1.45	1.44
1-18 1-24	1.10	1.23
1-25 1-31	2.24	2.22
2-1 2-7	0.18	0.17
2-8 2-14	1.33	1.24
2-15 2-21	0.98	1.20
2-22 2-28	0.77	0.51
3-1 3-7	0	0
3-8 3-14	0.86	0.81
3-15 3-21	0.67	0.67
3-22 3-28	0.36	0.28
3-29 4-4	0.48	0.64
4-5 4-11	1.50	1.21
4-12 4-18	0.36	0.31
4-19 4-25	2.32	2.22
4-26 5-2	0.54	0.52

Table 71. (Continued)

Date	In the Plantation	In the open area
5-3 5-9	0.08	0.06
5-10 5-16	0.45	0.38
5-17 5-23	0.08	0.10
5-24 5-30	0	0
5-31 6-6	0.94	0.97
6-7 6-13	0.50	0.58
6-14 6-20	1.07	1.08
6-21 6-27	0	0
6-28 7-4	0.48	0.65
7-5 7-11	0.37	0.31
7-12 7-18	1.21	1.54
7-19 7-25	0.55	0.58
7-26 8-1	1.26	1.59
8-2 8-8	1.02	1.61
8-9 8-15	3.87	4.76
8-16 8-22	1.00	1.07

Table 71. (Continued)

Date	In the plantation	In the open area
8-23 8-29	6.09	7.31
8-30 9-5	1.28	1.50
9-6 9-12	2.06	2.37
9-13 9-19	0	0

Table 72. Weekly records of the distance traveled by wind in number of miles at the two stations.

Date		In the plantation	In the open area
1936	9-21 9-27	0	292.2
	9-28 10-4	0	408.0
	10-5 10-11	0	273.1
	10-12 10-18	0	450.1
	10-19 10-25	0	197.7
	10-26 11-1	0	434.7
	11-2 11-8	0.3	524.0
	11-9 11-15	4.2	510.7
	11-16 11-22	11.9	479.0
	11-23 11-29	14.8	415.4
	11-30 12-6	26.5	447.3
	12-7 12-13	24.0	695.0
	12-14 12-20	32.8	519.7
	12-21 12-27	5.9	276.4
1937	12-28 1-3	6.6	377.1
	1-4 1-10	9.6	454.2

Table 72. (Continued)

Date	In the plantation	In the open area
1-11 1-17	29.4	428.8
1-18 1-24	41.8	622.8
1-25 1-31	83.4	746.6
2-1 2-7	47.6	481.5
2-8 2-14	38.4	553.1
2-15 2-21	40.4	390.0
2-22 2-28	51.5	584.4
3-1 3-7	49.8	398.0
3-8 3-14	57.8	525.4
3-15 3-21	44.6	544.7
3-22 3-28	61.5	632.0
3-29 4-4	63.8	491.5
4-5 4-11	63.7	539.5
4-12 4-18	69.7	655.7
4-19 4-25	67.1	586.2
4-26 5-2	67.1	464.5

Table 72. (Continued)

Date	In the plantation	In the open area
5-3 5-9	40.8	345.1
5-10 5-16	49.3	468.3
5-17 5-23	39.1	479.9
5-24 5-30	26.7	381.0
5-31 6-6	29.7	400.2
6-7 6-13	38.5	425.6
6-14 6-20	30.6	372.5
6-21 6-27	27.9	451.2
6-28 7-4	20.0	359.0
7-5 7-11	7.6	309.7
7-12 7-18	7.6	357.2
7-19 7-25	25.8	439.1
7-26 8-1	36.9	288.3
8-2 8-8	26.0	211.6
8-9 8-15	27.4	390.7
8-16 8-22	26.7	302.6

Table 72. (Continued)

Date	In the plantation	In the open area
8-23 8-29	21.5	294.5
8-30 9-5	15.7	268.5
9-6 9-12	19.5	348.3
9-13 9-19	16.1	317.4

Table 73. Weekly record of number of grams of water evaporated at two heights at the two stations.

Date		In the plantation		In the open area	
		Near the soil surface	At 6-foot height	Near the soil surface	At 6-foot height
1936	9-21 9-27	76.44	73.32	106.44	146.76
	9-28 10-4	49.14	46.02	74.88	90.06
	10-5 10-11	34.32	35.88	51.48	72.62
	10-12 10-18	63.96	59.28	79.56	128.77
	10-19 10-25	50.70	42.90	78.78	110.60
	10-25 11-1	35.08	33.77	63.12	111.44
	11-2 11-8	19.46	24.64	47.46	112.28
	11-9 11-15	22.40	27.30	54.60	138.20
	11-16 11-22	25.90	29.60	51.78	138.30
	11-23 11-29	17.20	18.20	34.00	96.10
	11-30 12-6	6.40	8.30	12.85	35.95
	12-7 12-13	6.50	8.30	12.85	35.95
	12-14 12-20	10.80	15.07	30.70	85.00
	12-21 12-27	4.77	7.10	14.77	45.90

Table 73. (Continued)

Date		In the plantation		In the open area	
		Near the soil surface	At 6-foot height	Near the soil surface	At 6-foot height
1937	12-28 1-3	4.77	7.10	14.77	45.90
	1-4 1-10	4.77	7.10	14.77	45.90
	1-11 1-17	3.50	4.50	9.00	42.00
	1-18 1-24	10.00	14.00	22.00	68.75
	1-25 1-31	10.00	14.00	22.00	68.75
	2-1 2-7	14.40	19.40	35.60	107.90
	2-8 2-14	16.10	25.40	43.50	120.60
	2-15 2-21	10.70	16.40	28.10	88.00
	2-22 2-28	20.72	33.60	71.96	174.58
	3-1 3-7	22.82	37.34	77.14	182.10
	3-8 3-14	28.07	46.69	90.09	200.90
	3-15 3-21	23.10	31.60	81.60	187.60
	3-22 3-28	36.60	56.80	123.00	255.40
	3-29 4-4	44.10	68.80	132.70	263.80
	4-5 4-11	36.20	63.00	79.2	161.60

Table 73. (Continued)

Date	In the plantation		In the open area	
	Near the soil surface	At 6-foot height	Near the soil surface	At 6-foot height
4-12 4-18	56.20	89.60	185.30	388.00
4-19 4-25	38.90	67.90	122.10	366.20
4-26 5-2	45.50	67.40	114.80	257.00
5-3 5-9	53.90	80.20	161.20	326.20
5-10 5-16	48.70	72.70	135.00	316.00
5-17 5-23	70.60	103.50	200.60	422.80
5-24 5-30	65.60	90.40	195.30	370.10
5-31 6-6	56.20	89.50	196.70	391.40
6-7 6-13	62.90	106.70	228.40	440.00
6-14 6-20	40.18	65.80	159.84	301.34
6-21 6-27	52.86	86.20	231.48	414.08
6-28 7-4	47.09	76.46	141.70	278.86
7-5 7-11	61.27	92.62	217.10	407.92
7-12 7-18	49.70	76.80	197.20	368.90
7-19 7-25	41.00	64.20	139.00	288.00

Table 73. (Continued)

Date	In the plantation		In the open area	
	Near the soil surface	At 6-foot height	Near the soil surface	At 6-foot height
7-26 8-1	39.50	58.40	145.00	275.40
8-2 8-8	30.50	59.00	130.50	263.00
8-9 8-15	27.30	43.50	100.00	252.50
8-16 8-22	31.00	57.30	139.00	308.20
8-22 8-29	12.50	22.50	64.00	174.50
8-30 9-5	20.00	37.30	82.00	259.00
9-6 9-12	22.20	31.40	54.00	189.50
9-13 9-19	33.30	40.30	76.00	266.00

Table 74. Weekly mean values of soil temperatures at two depths at the two stations.

Date	In the plantation						In the open area					
	Mean		Mean Maximum		Mean Minimum		Mean		Mean Maximum		Mean Minimum	
	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.
1936 9-21 9-27	69.58	68.47	76.57	72.14	64.29	64.71	74.63	74.22	88.24	80.80	65.96	68.71
9-28 10-4	66.07	65.41	71.71	68.00	62.00	62.86	68.12	68.37	77.14	72.43	61.84	64.53
10-5 10-11	67.40	66.30	71.43	68.57	64.14	64.00	70.49	69.84	77.71	73.00	64.71	66.57
10-12 10-18	62.73	61.99	68.29	64.57	58.86	59.43	64.16	64.28	73.00	68.00	57.71	60.71
10-19 10-25	60.31	59.19	67.43	63.00	55.43	55.71	62.00	61.60	73.29	66.71	53.86	56.29
10-26 11-1	52.58	51.83	57.57	55.00	48.14	49.14	52.23	53.05	61.57	57.29	45.57	49.00
11-2 11-8	56.40	55.26	60.00	57.43	53.00	53.00	58.02	57.51	64.86	60.14	52.57	54.57
11-9 11-15	49.68	49.12	53.29	51.29	46.29	46.71	49.30	50.20	56.43	53.00	43.57	46.86
11-16 11-22	43.70	42.44	47.43	45.43	39.00	39.29	41.26	41.84	50.43	46.00	34.86	37.29

Table 74. (Continued)

	Date	In the plantation						In the open area					
		Mean		Mean Maximum		Mean Minimum		Mean		Mean Maximum		Mean Minimum	
		Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.
	11-23 11-29	41.02	40.08	44.71	42.57	37.43	37.43	39.93	40.09	46.86	43.29	34.86	36.86
	11-30 12-6	39.17	37.71	42.14	39.86	36.86	36.14	38.68	37.89	43.86	40.43	34.71	35.86
	12-7 12-13	42.19	40.41	44.61	41.54	40.04	39.04	41.38	40.64	44.86	42.29	37.29	38.29
	12-14 12-20	40.42	39.09	42.43	40.71	38.46	37.84	40.24	39.89	44.57	41.86	37.29	38.00
	12-21 12-27	37.56	36.16	42.43	39.29	33.71	33.14	36.61	35.96	45.00	40.29	31.57	32.14
1937	12-28 1-3	46.42	44.62	48.29	46.29	44.43	43.29	47.72	46.40	50.43	48.14	44.71	44.86
	1-4 1-10	46.46	44.33	48.30	45.57	44.12	43.14	47.98	45.89	52.14	47.57	44.29	44.14
	1-11 1-17	48.84	49.28	50.71	48.81	47.16	46.33	50.26	49.51	53.71	51.14	47.00	48.00
	1-18 1-24	49.00	47.52	52.43	50.00	46.00	45.29	50.17	49.13	55.43	52.57	45.71	46.14

Table 74. (Continued)

Date	In the plantation						In the open area					
	Mean		Mean Maximum		Mean Minimum		Mean		Mean Maximum		Mean Minimum	
	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.
1-25 1-31	44.20	43.11	46.14	45.14	42.14	41.14	43.22	43.05	47.42	45.29	39.29	40.57
2-1 2-7	38.75	37.36	41.71	39.14	36.00	35.43	37.89	37.30	45.00	40.29	33.71	34.57
2-8 2-14	43.12	41.33	47.43	44.14	38.86	38.29	43.46	42.43	51.76	47.30	36.69	37.96
2-15 2-21	42.20	40.16	44.86	41.71	39.14	38.43	43.34	41.98	50.52	45.63	37.38	38.01
2-22 2-28	39.82	38.37	44.83	40.83	36.00	35.17	40.96	40.19	50.49	44.75	34.24	35.34
3-1 3-7	42.34	39.72	49.17	44.00	37.17	35.83	44.28	42.26	56.17	48.67	35.83	36.00
3-8 3-14	43.62	42.01	48.14	45.38	40.36	38.83	45.82	45.08	56.14	50.71	37.86	40.00
3-15 3-21	40.82	39.00	45.29	41.83	37.16	36.78	43.15	42.18	53.29	47.29	35.11	37.43
3-22 3-28	47.09	45.46	53.43	49.26	42.10	42.87	49.54	48.74	61.43	54.86	40.50	43.00

Table 74. (Continued)

Date	In the plantation						In the open area					
	Mean		Mean Maximum		Mean Minimum		Mean		Mean Maximum		Mean Minimum	
	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.
3-29 4-4	46.78	44.76	53.43	49.29	40.89	40.47	50.35	48.72	63.14	55.14	40.14	42.14
4-5 4-11	52.36	50.65	56.00	53.00	48.86	48.16	56.48	54.09	65.20	58.00	49.86	50.29
4-12 4-18	51.95	49.84	58.70	54.63	43.46	44.44	55.43	53.90	68.00	60.43	44.86	47.00
4-19 4-25	58.17	56.34	62.03	58.69	54.20	54.00	62.57	61.01	71.43	65.29	56.00	57.00
4-26 5-2	53.39	51.82	58.57	54.86	49.14	48.80	56.92	55.63	67.43	60.29	49.14	51.14
5-3 5-9	58.41	56.02	66.14	60.43	52.43	52.00	63.15	60.88	77.14	67.14	53.14	54.29
5-10 5-16	61.94	59.52	68.57	63.43	56.57	56.14	65.67	63.44	76.43	68.00	57.57	58.71
5-17 5-23	66.42	62.85	76.00	68.43	58.57	57.71	71.08	67.88	85.86	74.57	59.14	60.71
5-24 5-30	71.48	68.30	80.00	73.29	65.00	64.14	78.04	74.80	92.71	81.29	67.71	68.71

Table 74. (Continued)

Date	In the plantation						In the open area					
	Mean		Mean Maximum		Mean Minimum		Mean		Mean Maximum		Mean Minimum	
	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.
5-31 6-6	74.50	71.52	83.00	76.14	68.00	67.14	81.24	78.64	94.86	85.57	71.14	72.29
6-7 6-13	72.74	70.89	79.86	75.29	67.29	67.29	79.03	77.56	91.57	84.14	70.29	71.57
6-14 6-20	73.91	72.13	80.71	76.43	68.86	68.86	79.56	78.30	91.14	84.57	72.14	73.71
6-21 6-27	75.18	72.89	83.14	77.42	69.00	68.71	81.63	79.80	94.57	86.14	72.14	73.43
6-28 7-4	72.59	71.20	79.57	75.57	67.00	67.57	79.51	78.41	92.86	84.71	70.57	73.14
7-5 7-11	75.04	72.85	82.38	77.09	69.46	69.36	81.43	80.23	92.71	86.43	73.29	74.29
7-12 7-18	79.42	77.51	87.14	82.00	73.71	73.43	86.13	85.14	97.57	91.57	78.00	79.43
7-19 7-25	72.31	71.64	77.14	74.43	68.00	68.86	77.52	77.37	85.29	81.29	71.00	72.86
7-26 8-1	73.33	72.07	79.14	75.29	69.71	69.71	78.57	77.88	88.86	82.57	72.86	74.14

Table 74. (Continued)

Date	In the plantation						In the open area					
	Mean		Mean Maximum		Mean Minimum		Mean		Mean Maximum		Mean Minimum	
	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.	Surface	6 in.
8-2 8-8	73.31	72.24	78.57	75.14	69.00	68.86	78.43	77.69	87.29	82.00	72.00	73.00
8-9 8-15	71.47	71.15	77.53	75.38	71.04	71.52	78.24	77.88	85.86	81.71	73.71	74.86
8-16 8-22	74.09	73.00	79.71	76.36	69.93	69.86	78.83	78.19	87.71	82.86	72.43	73.86
8-23 8-29	72.97	72.52	76.07	74.04	71.75	71.36	77.81	77.56	84.00	80.43	74.57	75.29
8-30 9-5	74.24	73.48	78.43	75.86	71.29	71.14	79.17	78.37	86.29	82.14	74.43	75.00
9-6 9-12	68.86	68.70	69.89	69.29	67.00	67.32	72.48	72.68	77.14	74.43	69.00	70.57
9-13 9-19	64.75	64.67	69.14	67.86	60.86	61.57	67.88	68.36	75.14	71.86	62.29	64.71

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Biography

The writer, Yen-Chieh Wang, was born in Peiping, China, on May 8, 1908. He was educated in the public and middle school at Peiping. In the autumn of 1925, he entered National Tsing Hua University at Peiping, China, and studied there for four years with Biology as his major. He graduated from Tsing Hua University in July, 1929, with the degree of Bachelor of Science.

After graduation he held a position in the Biological Laboratory of the Science Society of China as a research assistant from 1929 to 1930. Later he was assistant in the Department of Biology at Tsing Hua University, Peiping, China, from 1930 to 1933, and from 1933 to 1935 he was instructor in botany at Kwangsi University, Wuchow, Kwangsi, China.

In October, 1935, he entered the Graduate School of Cornell University, Ithaca, New York, where he pursued studies in forestry under the supervision of the Department of Forestry. He received the Master of Science degree at that institution in June, 1936.

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